PROCEEDINGS OF THE GEOLOGISTS' ASSOCIATION

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G5
vol.67
1956/57

VOLUME SIXTY-SEVEN : 1956-7

EDITED BY A. J. DOLLAR

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ERRATA

Page 127, line 26 from top, *for* anatate *read* anatase.

Page 129, in Key to Fig. 2, *for* staurolite *read* rutile; *for* rutile *read* staurolite.

Aids to Authors of Papers and Reports intended for the Proceedings of the Geologists' Association

'Be brief' *Shakespeare*[1]

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ABSTRACT: Notes on the preparation and submission of papers and reports for the PROCEEDINGS are offered by the Council of the Geologists' Association to facilitate publication of such works with the least possible expense and delay.

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1. GENERAL

A PAPER or report for the PROCEEDINGS OF THE GEOLOGISTS' ASSOCIATION, should be concise, orderly, accurate and fully documented. Clarity and style are improved by the use of short words, short sentences and simple phrases. Illustrations should be few and carefully chosen. Line drawings are preferable to photographs, and diagrams to equivalent numerical tables. Close attention to all these matters is essential in view of printing costs.

If the work is a paper, a typed copy, with any illustrations, should be sent to the Publications Secretary for consideration by the Publications Committee, and an identical copy of text and illustrations retained by the author.

Normally, the paper should be between two and nine thousand words in length, and should not exceed twelve thousand words. It should be accompanied by an abstract in not more than two hundred words which should be intelligible without reference to the paper.

---

[1] *Measure for Measure*, v, i, 26.

The Publications Committee will appoint one or more referees who will report on the suitability of the paper for publication. The comments and suggestions of the referee or referees may be forwarded to the author through the Publications Secretary.

An invitation to read a paper does not imply acceptance of the paper for publication. When a paper or report is accepted by the Association it becomes the property of the Association, and copyright of the work rests with the Association.

If the work is a report of a field meeting or demonstration, a typed copy, with any illustrations, should be sent to the Field Meetings Secretary, who will arrange for its consideration by the Publications Committee.

2. TEXT

Authors can see approved forms of layout for papers and reports in recent volumes of the PROCEEDINGS.

A clear copy, in original typescript (*not* a carbon copy) should be on one side of quarto paper of sufficient quality for correction in ink. Soft duplicating paper is unsuitable. Wide margins and double spacing are essential. Pages should be numbered consecutively, and clipped (but not stapled) together. Authors' corrections of the text must be in black or dark blue ink. Typographic conventions are the concern of the Editor, but an author's suggestions may be indicated in marginal notes.

(a) Papers

In the case of a paper, the *title* should be precise, brief and in capital letters (*not* underlined), succeeded by the full *name of the author*. Unless it is very short, the paper should have a *table of contents*, involving only primary headings, if possible, which headings must correspond with those in the body of the paper. Following this should be the *abstract*, in which a concise statement of new evidence and a summary of conclusions is given. Next should come the *introduction* to the paper, in which the relation of the author's work to that of others should be discussed. Then follows the *body of the paper*, at the end of which the *main conclusions* should be stated, after which *acknowledgments* should be made of any aid received during the course of the work; *explanations* should be given *of any plates*, and a *list of references* to appropriate literature added. Finally, if the paper is read before the Association, and a discussion ensues, the author should provide the Editor with written *replies to contributions to the discussion* of his paper when the Editor sends him the relevant written contributions.

(b) Reports

A report of a field meeting or demonstration should begin with a short clear *title*, followed by the full *name*(*s*) *of the author*(*s*) *of the report.* Next should be given the full *name*(*s*) *of the director*(*s*) of the meeting or demonstration, and the *title* and *author*(*s*) of any *supplementary note*, e.g. a faunal list. Following this should be a *list of contents*, unless the report is very short. The ensuing brief *introduction* should preface the *main account.* In the case of a field report, unless it is of a one-day meeting, it should be given in the form of a *daily itinerary*, with the *name*(*s*) *of the director*(*s*) included under each of the daily headings. On the other hand, when the report is of a demonstration, this part of the account should be given under the headings of *buildings or departments visited*, or in some similar manner. Next follow *acknowledgments*, the *explanation of any plate*(*s*) involved and a *list of references.* Finally comes any *supplementary note* relating to the main report.

(c) Headings

Headings should be extremely short and of not more than three kinds: primary, secondary and tertiary.

A primary heading is placed in the centre of a page and preceded by an arabic numeral which is not enclosed between parentheses (e.g. '1'). A secondary heading is placed in the centre of a page, but preceded by a small roman letter, in parentheses (e.g. '(a)'). A tertiary heading is placed at the beginning of the first line of the section to which it refers, but is preceded by a small roman numeral (e.g. '(i)'), and followed by a full stop. These three kinds of heading are illustrated in this pamphlet.

In typescript, headings should *not* be underlined.

(d) Footnotes

Footnotes are undesirable. When deemed indispensable they should be referred to in the text by small figures, placed above the line at appropriate places, and corresponding notes inserted in the typescript immediately below these places, between parallel lines, thus.[1]

---

[1] This is the manner in which a footnote should be inserted.

Such footnotes should be numbered serially throughout the typescript.

(e) Numerical Quantities

The unit in terms of which any numerical quantity is expressed should be given, together with its metric equivalent unless the quantity has been given in metric units initially. Also, *insert* a terminal *s* in hrs., tons, yds., but *omit* it in cm., gm., in., lb., min., mm., oz., and sec.

It is important to remember that the accuracy of numerical quantities are implied by the number of significant figures to which they are given, e.g. lengths, areas, weights, frequencies, refractive indices.

For numerical values less than 1, the decimal point should be preceded by a '0', e.g. 0.75 mm.

Percentages by weight should be distinguished from percentages by volume.

In algebraic expressions, the meanings of symbols must be stated clearly.

(f) Tables

Tables, being expensive to set in type, should be as few and as simple as possible. Small tables can be included in the text, but large ones should be typed on separate pages and their positions in the text indicated thus:

Table 1 hereabouts

When planning a table, authors should consider what will fit into a page of the PROCEEDINGS. Tables should not be completely enclosed by lines unless this is essential for the sake of clarity.

Tables which are intricate or unusually large can be reproduced more economically by line blocks than from type. Tables from which blocks are to be made must be carefully drawn in accordance with the appropriate notes on the preparation of illustrations (Section 3, p. xiii). Typewriting is *not* suitable and lettering must be neat.

In tables a distinction should be drawn between a result giving a nil value (shown '0' or 'nil') and an entry showing that no observation was made.

(g) Localities

Localities quoted in a paper or report should be marked on the maps and sections which illustrate the work. Also, the longitudes and latitudes (National Grid References for Great Britain) of such localities should be given, in parentheses, immediately after their names, in the text, especially when discussing places situated in unfenced country.

(h) Geological Terms

(i) *Mineralogical and Petrological.* The names of minerals, rocks and structures require no initial capitals (e.g. quartz; basalt; fault), unless they form part of the name of a stratigraphical unit (e.g. Dolomitic Conglomerate; Wrekin Quartzite), or of a particular well-known structure (e.g. Great Glen Fault).

A number of compound mineralogical and petrographical terms need hyphens (e.g. soda-microcline; biotite-hornblende-gneiss). Abbreviations (e.g. Or; An; Mg-rich) should be used sparingly.

Chemical formulae of minerals may be expressed either in the expanded form (e.g. $K_2O.Al_2O_3.\ 6SiO_2$) or in the contracted form (e.g. $KAlSi_3O_8$).

In giving a rock mode, its method of determination, and its relation to volume or weight, should be specified.

British usage should be adopted wherever possible (e.g. in the spelling of 'felspar'; in the application of the term 'diabase').

(ii) *Stratigraphical and Palaeontological.* Such a term as 'band', 'bed', 'formation', 'group', 'series', 'stage', 'system' or 'zone', carries an initial capital, as does a rock name, if it forms part of the title of a recognised stratigraphical unit. A term such as 'epoch', 'era' or 'period', relating to time, bears no initial capital. Examples of the first group of terms are as follows:

Achanarras Band
Ludlow Bone Bed
Chesapeake Formation
Diabaig Group
Cementstone Series
Maentwrog Stage
Jurassic System
Belemnitella mucronata Zone

and

Haffield Breccia
Chalky Boulder Clay
Lower Chalk
London Clay
Brora Coal
Norwich Crag
Contorted Drift
Fuller's Earth
Cambridge Greensand
Millstone Grit
Claxby Ironstone
Durness Limestone
Purbeck Marble
Etruria Marls
Great Oolite
Penrith Sandstone
Lower Ludlow Shales
Cromer Till

When the name of a stratigraphical unit includes the name of a fossil species, the generic and specific names must be quoted in full, either at the first mention of the unit or in a stratigraphical table; elsewhere, provided there is no ambiguity, the generic name may be abbreviated to its initial letter, followed by a full stop, or may be omitted. When the name of a unit includes a generic name but not a specific name, the generic name is always given in full.

Thus: *Micraster cor-anguinum* Zone
or *M. cor-anguinum* Zone
or *cor-anguinum* Zone

and *Trigonia* Beds

Care should be taken in applying such terms as 'Charnian' and 'Charnoid'.

(i) Palaeontological Descriptions

Generic and specific names are printed in italics, and specific names begin with small letters. The full generic name of a species must be given when the latter is first mentioned: elsewhere it may be abbreviated to its initial capital letter, followed by a full stop, provided that the abbreviation does not confuse readers. The author of each species name should be given, usually once in the course of the paper, either when first mentioned, or in a list or table. The author's name should not be abbreviated, and initials should be included where necessary (for example, 'J. de C. Sowerby' or 'J. Sowerby', not merely 'Sow.').

Systematic descriptions of fossil species should be given in the following order:

Name and reference to plate and figure number(s).
Synonymy, with each item given as follows: date, genus, species, author of species, author of work cited, title of periodical or work (if a separate publication), volume, page, plate and figure number(s).
Diagnosis.
Material, with fixation of holotype.
Locality and horizon, both being indicated as precisely as possible.
Description.
Remarks.

(j) References

The accurate statement and checking of references to literature is a responsibility of the author. In both connections it is essential to *consult the original publications* cited.

References should *not* be given in the form of footnotes but gathered in a list, headed 'References', at the end of the paper or report, and arranged alphabetically under authors' names. Works by any particular author should be arranged chronologically. If two or more of these works were published in the same year, they would be distinguished thus: 1932 . . . , 1932a . . . , 1932b . . .

The general form of a reference to a work in a periodical should be: name(s) and initial(s) of author(s) (in capital letters); year of publication; title of work; title of periodical (abbreviated, or in full if there is no accepted abbreviation); series number, if any, in parentheses; volume (arabic numerals, bold type, *not* preceded by 'vol.'); part number, if any, in parentheses; page(s) (*not* preceded by 'p.' or 'pp.').

When the publication is a book, or other separately published work, to the foregoing particulars are added the edition (if more than one) and the place of publication. Examples are as follows:

(i) for a paper, or similar work,

SIBLY, T. F. 1920. The Carboniferous Limestone of the Cardiff District. *Proc. Geol. Ass., Lond.*, **31**, 76–92.

(ii) for a book, or equivalent work,

Tyrrell, G. W. 1946. *The Principles of Petrology*, 8th ed. London.

In the text, mention of such references can be made as follows: (Sibly, 1920, p. 76) or (Tyrrell, 1946) or 'Tyrrell (1946) draws attention to . . .' If there are two authors of a work, both are quoted (e.g. Marr & Nicholson (1888)): if there are more than two authors, then all are mentioned on the occasion of the first quotation, but subsequently only the first of them, with the addition of *et al.*

Abbreviations for the titles of periodicals should be those given in the *World List of Scientific Periodicals* (1952, 3rd ed., London: Oxford University Press), as exemplified below.

Amer. J. Sci.
Amer. Min.
Ann. Paléont.
Brit. reg. Geol.
Bull. geol. Soc. Amer.
Bull. geol. Surv. G.B.
Bull. Soc. géol. Fr.
Bull. volcan.
C.R. Acad. Sci., Paris.
Econ. Geol.
Geogr. J.
Geol. Mag.
J. Geol.
J. Geomorph.
Geophys. J.
J. Glaciol.
J. Paleont.
J. sediment. Petrol.
Manchr. geol. Min. Soc. Trans.
Mem. geol. Surv. U.K.
Miner. Abstr.
Miner. Mag.
Min. Mag., Lond.
Nature, Lond.
Palaeontogr. Soc. [*Monogr.*]
Phil. Mag.
Phil. Trans.
Proc. Geol. Ass., Lond.
Proc. Lpool geol. Soc.
Proc. R. Irish Acad.
Proc. Yorks. geol. (*polyt.*) *Soc.*
Quart. J. geol. Soc. Lond.
Spec. Rep. Min. Resour. G.B.
Summ. Progr. geol. Surv., Lond.
Trans. Edinb. geol. Soc.
Trans. geol. Soc. Glasg.
Trans. Hull geol. Soc.
Trans. Instn Min. Metall., Lond.
Trans. R. geol. Soc., Cornwall.
Trans. roy. Soc. Edinb.
Z. dtsch. geol. Ges.
Z. Kristallogr.

The title of any periodical for which there is no recognised abbreviation should be given in full.

3. ILLUSTRATIONS

Illustrations of papers and reports are either text-figures or plates. In all but exceptional cases they should be black-and-white reproductions of line drawings or photographs. They are expensive. Coloured reproductions, being even more expensive, are rarely used. The reproduction of photographs by costly half-tone blocks calls for special 'art' paper. It follows that illustrations must be few and of the highest quality.

Originals should be about twice the linear dimensions of final reproductions (Fig. 1). Normally, the greatest permissible size for a text-figure

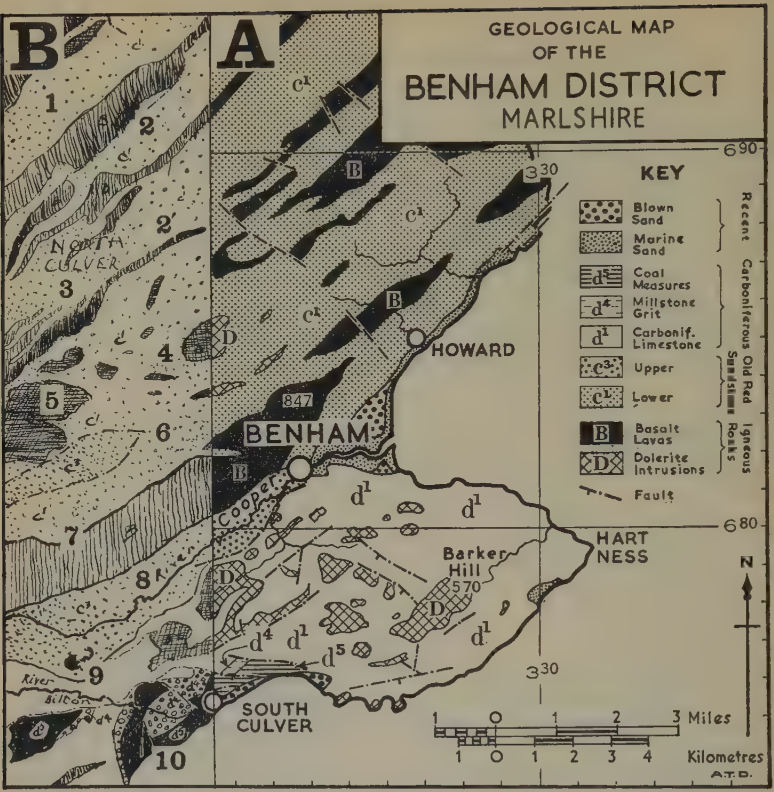


Fig. 1. Representation of the geology of an imaginary district in the British Isles, reproduced from an original line drawing of twice the linear dimensions of this illustration

AREA A. Representation giving satisfactory reproduction

Outcrop symbols of ‘B’, ‘D’, ‘marine sand’, ‘blown sand’ and all outlines, are drawn by hand. Outcrops of ‘c^1’ and ‘c^3’ are distinguished by mechanical stipples (‘Zip-a-Tone’); outcrops of ‘d^4’ and ‘d^5’ are distinguished by mechanical shading (‘Zip-a-Tone’).

Note results of using clear, uniform lines and numerals, and relatively wide spacing of details. ‘Uno’ pens and stencils were used for lettering in the title, key and place names: a script writing pen was used elsewhere.

AREA B. Representation giving unsatisfactory reproduction

In the area:
1. *Dots* too small, not circular and distributed irregularly.
2. 2′. *Shading* not parallel and so crowded as to coalesce.
3. *Letters* too thin and badly shaped.
4. *Reference letter* (‘D’) masked by close cross-hatching.
5. *Cross-hatching* by lines which are too thin, too closely packed and intersecting at an inappropriate angle. Also, the lines in each set are not parallel.
6. *Fault lines* too thin and irregularly shaped.
7. *Junction lines* not of uniform thickness.
8. *Lettering* too small and imperfectly formed.
9. *Error* (ink blot) incompletely erased.
10. *Ornament* poorly executed and inappropriate for beds involved.

Note results of using small dots, thin irregular lines, crowded details and ill-formed letters and numerals, as made by a mapping pen.

is 4 in. x 6 in. (102 mm. x 152 mm.); larger illustrations call for folded sheets ('throw-outs') which are proportionately costly because of the extra expense incurred in folding. It is advantageous if the set of drawings or photographs for any one paper or report are so made that they have the same factor of reduction throughout. On the back of each illustration the reference number of the figure or plate, the caption (if any) and the author's name should be written, clearly but lightly, in soft pencil.

Line drawings must be executed in indian ink, or process black ink, on Bristol board, scraper board or unfolded, stout, smooth, white paper (*not* cartridge paper or water-colour drawing paper). Should it be necessary to submit the original as a tracing, some of the proprietary brands of plastic tracing material (e.g. 'Kodatrace' or 'Ethylon') are better than tracing cloth or white detail paper.

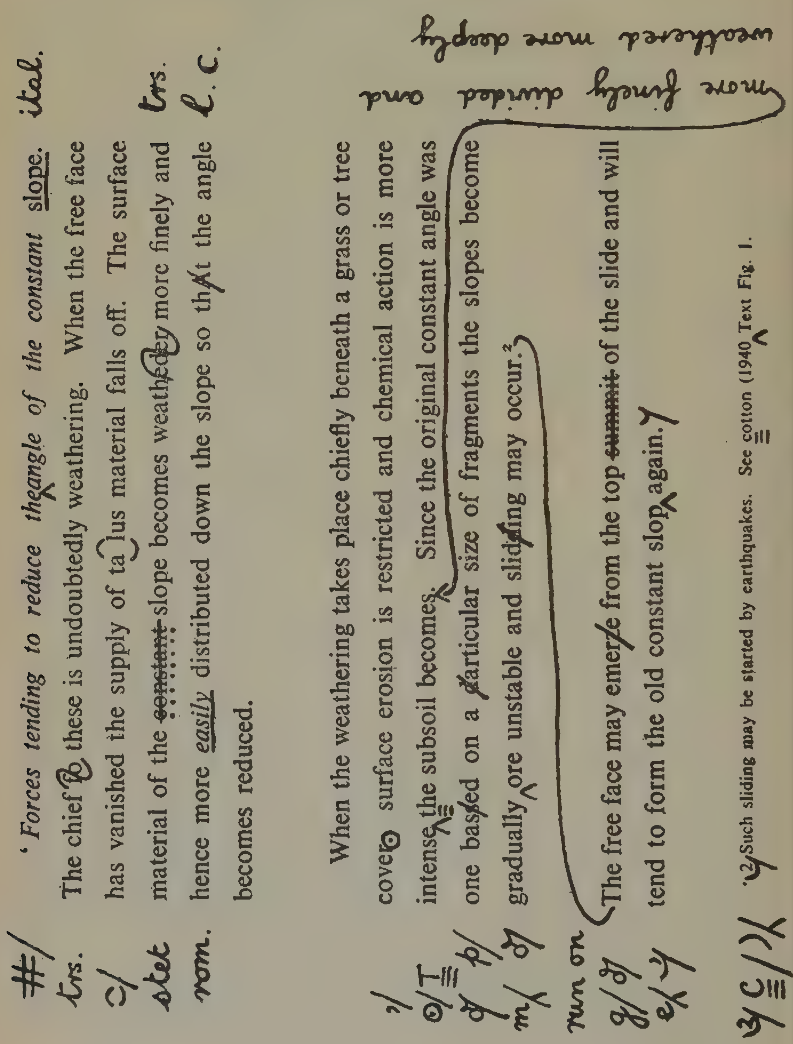
Letters and numerals must be neat and of a size to allow for reduction. At normal reading distances it is difficult to recognise either a letter or a numeral which, on reproduction, is less than 1 mm. in height. Usually, both letters and numerals should be completed before the remainder of a drawing. Stencils such as 'Uno', or 'Wrico', or 'Standardigraph' are of assistance in these connections.

All lines must be absolutely black, and of a thickness to allow for reduction by one half. As far as possible they should be uniform in width, with sharp edges. Thin or tapering lines, and small dots or dashes, such as are made by mapping pens (as distinct from the ruling pens used in machine drawing, or the script pens employed in ticket writing), are often lost in reproduction. Lines of shading must be bold, and widely spaced, but care should be taken that geological boundaries remain the most prominent lines on the map. Solid black should be used only for small areas which are not too close together. Circles and dots should be as large as possible, so as to ensure clear reproductions. Arrows should be small, neat and symmetrical. Symbols used to distinguish areas on maps and diagrams must not be overcrowded. Mechanical stipples or shading (e.g. 'Zip-a-Tone' or 'Plastitone') may be used here with advantage. The original drawing, intended for reduction to one-half, should be read satisfactorily when viewed from a distance of four feet. If details are not clearly visible at that distance there is a risk that the final illustration will suffer, either through thinning of the lines in the block-making process, or through clogging of the block with ink, or both.

Deletions are best effected by painting out with the material known as 'process white'. Chinese white should *not* be used. Alterations on blocks are usually difficult or impossible.

Maps must bear a full title (incorporating the county or district involved), a graphic scale of miles, yards or feet, a line or arrow to show true north, and lines of longitude and latitude (ends of National Grid lines, for

The Correction of Printers' Proofs: some Symbols and their Applications



‘*Forces tending to reduce theangle of the constant* slope. The chief fo these is undoubtedly weathering. When the free face has vanished the supply of ta lus material falls off. The surface material of the ~~constant~~ slope becomes weathedery more finely and hence more *easily* distributed down the slope so thAt the angle becomes reduced.

When the weathering takes place chiefly beneath a grass or tree cover surface erosion is restricted and chemical action is more intense the subsoil becomes. Since the original constant angle was one bassed on a darticular size of fragments the slopes become gradually ore unstable and sliddng may occur.²

The free face may emerze from the top ~~summit~~ of the slide and will tend to form the old constant slop again.

2Such sliding may be started by earthquakes. See cotton (1940 Text Fig. 1.

CORRECT COPY

‘*Forces tending to reduce the angle of the constant slope.* The chief of these is undoubtedly weathering. When the free face has vanished the supply of talus material falls off. The surface material of the constant slope becomes weathered more finely and hence more easily distributed down the slope so that the angle becomes reduced.

When the weathering takes place chiefly beneath a grass or tree cover, surface erosion is restricted and chemical action is more intense. The subsoil becomes more finely divided and weathered more deeply. Since the original constant angle was one based on a particular size of fragments the slopes become gradually more unstable and sliding may occur.[2] The free face may emerge from the top of the slide and will tend to form the old constant slope again.’

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[2] Such sliding may be started by earthquakes. See Cotton (1940) Text Fig. 1.

localities in Great Britain) round the margins. The addition of a metric scale, expressed in suitable units, is useful to foreign readers.

A columnar representation of the rock succession should be included in the key, numbered upwards from the base and showing the conventional symbols used to distinguish outcrops on the accompanying map. Accepted symbols should be used for geological boundaries and structural features.

Failure to adhere to these suggestions may make an original drawing unsuitable for reproduction.

Photographs should be unmounted, sharp, glossy, black-and-white prints, showing good contrast and ought to be free from scratches, folds or cracks. If necessary, they should be neatly re-touched with process black, process white, and mixtures of the two. Faded or discoloured prints are unsuitable for the preparation of half-tone blocks.

The magnifications of photomicrographs or drawings of microscope fields, or of photographs or drawings of fossils, should be given (e.g. × 10; ×0.65). Photomicrographs should also include an indication as to whether their negatives were made in plane polarised light (P.P.L.), or between crossed nicols (X.N.).

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Corrections are permissible on the first or galley proof, which is forwarded to the author by the Editor together with the typescript and a note of the author's entitlement of free reprints. The corrections should be made in black ink, according to accepted practice (see pp. xvi–xvii), and should include clear marginal notes showing where tables, text-figures or plates are to be inserted (e.g. 'insert Table 2 here'; 'Fig. 4 hereabouts'; '5th Plate here'). The proof and author's typescript should then be returned to the Editor together with a note of any reprints desired by the author at his own expense. This note will be forwarded by the Editor to the publishers of the PROCEEDINGS, from whom the cost of such reprints can be ascertained. Any subsequent correspondence relating to these reprints must be conducted by the author with the publishers—*not* through the Editor. Normally, a single author is entitled to twenty-five free reprints of his work; two or more authors share fifty free reprints between them.

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If the author is abroad, his galley and page proofs should be read and corrected by a deputy, living in the British Isles, whose name and address are given to the Editor. If the deputy is to receive reprints on behalf of the author, both the Editor and the publishers of the PROCEEDINGS should be notified accordingly.

5. RECOMMENDED WORKS

The following works are useful in the preparation of geological manuscript and illustrations:

General:

GEOLOGICAL SOCIETY OF LONDON. 1952. *Notes on the Preparation of Papers for Publication in the Quarterly Journal.* London: Geological Society of London.

ROYAL SOCIETY. 1950. *General Notes on the Preparation of Scientific Papers.* London: Cambridge University Press.

HART, H. 1954. *Rules for Compositors and Readers at the University Press, Oxford.* 36th ed. London: Oxford University Press.

Dictionaries:

Concise Oxford Dictionary. 1951. 4th ed. Oxford: Clarendon Press.

Chambers's Technical Dictionary. 1953. 8th ed. Edinburgh: Chambers.

COLLINS, F. H. 1956. *Authors' and Printers' Dictionary*. 10th ed. Oxford: Oxford University Press.

FOWLER, H. W. 1926. *A Dictionary of Modern English Usage*. Oxford: Oxford University Press.

ROGET, P. *Thesaurus of English Words and Phrases*. 1952. Revised ed. by D. C. Browning. London: Dent.

Style:

FOWLER, H. W. & F. G. FOWLER. 1930. *The King's English*. 3rd ed. Oxford: Oxford University Press.

GOWERS, E. 1956. *The Complete Plain Words*. Revised ed. London: H.M. Stationery Office.

Proceedings of the

GEOLOGISTS' ASSOCIATION

Some New Liassic Terebratuloids

by D. V. AGER

Received 27 January 1955

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ABSTRACT: One new sub-species and two new species of British Liassic terebratuloids are described and figured. The first is an excellent example of a fossil geographical sub-species. One of the new species is an unusual sulcate terebratulid, and may belong to an undescribed genus. The other is a zeilleriid which possesses interesting internal structures.

1. INTRODUCTION

RECENTLY the author has completed a detailed study of the brachiopods of the British Middle Lias, with special reference to their geographical distribution. Of the many species studied, the rhynchonelloids proved to be the most varied and the least well known. These are to be described in a monograph of all the British Liassic rhynchonelloids. Among the terebratuloids, nearly all the short-looped forms (family Terebratulidae) belong to the genus *Lobothyris*. This has been revised by Dr. H. M. Muir-Wood (1934), and comprises but a few, fairly well-known forms. Dr. Muir-Wood has also revised the Liassic long-looped genera (family Zeilleriidae) though this work has not yet been published. Therefore the author does not propose to attempt a detailed study of the Middle Liassic terebratuloids at this stage. In the course of his work, however, three undescribed forms were discovered which require special consideration and taxonomic distinction. Each of these has special points of interest which are discussed in the present work.

The author would like to express his thanks to Dr. H. M. Muir-Wood of the British Museum (Natural History) for much valuable criticism. He is also grateful to Mr. A. Hallam for information about the new sub-species and for the loan of specimens, and to Mr. J. F. Jackson for help with

specimens from Dorset. The author's wife assisted considerably in all aspects of the work.

2. SYSTEMATIC DESCRIPTIONS

Family: TEREBRATULIDAE

Genus: **LOBOTHYRIS** S. S. Buckman, 1918; emended H. M. Muir-Wood, 1934

Species: *LOBOTHYRIS PUNCTATA* (J. Sowerby)

Lobothyris punctata clevelandensis subsp. nov.

Plate 1, Figs. 1 a–c, 2 a–b, 3 a–c, 4 a–b, 5 a–b

1882. *Terebratula punctata* var *Edwardsii* Davidson; Haas & Petri, pl. viii, figs. 7, 11.

Diagnosis. Small to medium-sized variants of *Lobothyris punctata*. Pyriform outline, maximum width near the anterior end of the shell. Growth-lines conspicuous. Beak strong, projecting, slightly incurved. Pedicle-opening large, circular.

Type specimens. Holotype, specimen in the British Museum (Natural History) (B.32486). This is recorded as having come from an ironstone band in the Middle Lias (*spinatum* zone) at Eston Mine in the Cleveland district of Yorkshire.

Paratype 1, in the author's collection (J.510/4), from the Marlstone Rock-bed (*spinatum* zone) at East Adderbury near Banbury in Oxfordshire.

Paratype 2, in the author's collection (J.1002/2), from the *margaritatus* zone at Huntcliff near Saltburn in Yorkshire.

Paratype 3, in the British Museum (Natural History) (47247), from the Middle Lias, probably at Staithes in Yorkshire.

Paratype 4, in the Geological Survey Museum (26374), from the Upper Lias (*jurense* zone, *moorei* sub-zone) at Blea Wyke in Yorkshire.

Distribution. This sub-species occurs as part of the normal range of variation of *Lobothyris punctata* s.s. in the Marlstone Rock-bed of the English Midlands. The first paratype is an example of such a variant from a large community. It appears to be concentrated at certain localities (for example near Byfield in Northamptonshire), and Mr. A. Hallam has observed 'a notable incidence of this form in . . . a band half-way up the Rock-bed' in the Tilton area of Leicestershire (personal communication). There are, however, no certain and rigid limits to the form in that region. So far it has not been recognised in the Lias south-west of the Moreton-in-Marsh axis, or in the Hebrides. In Yorkshire, short-looped terebratuloids are very scarce in the Middle Lias, and the otherwise ubiquitous *Lobothyris* *punctata* is represented almost entirely by rare specimens of the variant described here. It is found in the *spinatum* zone of the Cleveland district and, more commonly, as dwarfs in the *margaritatus* zone on the coast. Occasional specimens are also known from the *davoei* zone of the Lower Lias, and even fewer from the *jurense* zone of the Upper Lias.

Dimensions of types. Holotype, length 26.7 mm., width 20.5 mm., thickness 12.8 mm.

Paratype 1, length 24.2 mm., width 17.4 mm., thickness 13.5 mm.
Paratype 2, length 13.7 mm., width 10.1 mm., thickness 6.9 mm.
Paratype 3, length 32.5 mm., width 24.0 mm., thickness 14.8 mm.
Paratype 4, length 40.4 mm., width 33.6 mm., thickness 21.7 mm.

Description. (a) *External characters.* In the *spinatum* zone of the English Midlands, this sub-species displays the same general range in dimensions as were recorded for *Lobothyris punctata* by Alkins (1923). Similar dimensions have been observed in the form found at the same horizon in the Yorkshire area. The variants found in the *margaritatus* zone of Yorkshire are, however, always much smaller (see, for example, Paratype 2). This is also true for the rare specimens found in the *davoei* zone (e.g. specimen in the British Museum (Natural History) (B.32849), from Hummersea near Skinningrove). In both cases this is thought to have been the effect of dwarfing due to an unfavourable environment. The very rare specimens from the Upper Lias, however, are much larger in size (as exemplified by Paratype 4), though not enough specimens are known to make deductions from this fact.

L. punctata clevelandensis is pear-shaped in outline, with a fairly acute apical angle, and an axis of maximum width near the anterior end of the shell. The pedicle valve is strongly convex, and the brachial valve only slightly so, or almost flat. The anterior commissure is rectimarginate. Growth-lines are usually conspicuous. The beak is strong and incurved, usually projecting at right angles to the plane between the valves, and nearly always hiding the delthyrium. Beak-ridges are well-marked in smaller specimens, but become faint in normally developed adults. The pedicle-opening is large, circular and epithyrid.

(b) *Internal characters.* These are as described by Muir-Wood (1934) in *L. punctata* s.s.

Discussion. The characters noted in the diagnosis serve to distinguish this sub-species from *L. punctata* s.s., as represented by Sowerby's original figure and Muir-Wood's lectotype. Thus *L. punctata clevelandensis* is usually below average size for the species, its axis of greatest width is nearer the anterior margin, its growth-lines are more noticeable and its beak is stronger. However, it is not suggested that there is any absolute biological distinction here. On the evidence of the Midlands alone, there do not appear to be sufficient grounds for separating this sub-species, though Mr. Hallam has found it of some slight stratigraphical use. Only in Yorkshire does this variant become really significant, since practically all the specimens examined from the Yorkshire Lias have proved to be of this type. Therefore it provides an excellent example of a geographical sub-species, persisting in a single area throughout a considerable period of geological time. In this connection it has been discussed by Ager (1956). This may well be a case of geographical isolation as a factor leading to the production of a new sub-species and ultimately, perhaps, of a new species.

Lobothyris punctata appears to be a very widespread species in the Lias of Europe, and several sub-species or varieties have been proposed by various authors. Many of these are of doubtful validity, and the only figured specimen which seems to match the form described here is the one from eastern France quoted in the synonymy. This occurrence may be significant, since Yorkshire Liassic brachiopod faunas have many points in common with those of north-eastern France and western Germany, but there is not a great deal of evidence to rely on in this case.

L. punctata clevelandensis is often strongly homoeomorphic with the long-looped form *Zeilleria darwini* (Eudes-Deslongchamps), which was originally described from the Middle Lias of Normandy.

Remarks. The sub-specific name is taken from the Cleveland district of north Yorkshire, which appears to have been the special habitat of this form.

Genus: **TEREBRATULA** Müller, 1776; *sensu lato*

'Terebratula' reversa sp. nov.

Plate 1, Figs. 6 a–c

Inversithyris inversa S. S. Buckman (MS.)

Diagnosis. Medium-sized terebratulid, up to about 35 mm. long, 30 mm. wide and 20 mm. thick. Sub-circular in outline, almost equally biconvex. Anterior commissure rectimarginate to plano-sulcate. Beak small, rounded, incurved; pedicle-opening small, rounded, epithyrid. Internal characters as in *Lobothyris*, but for the extension of the umbonal cavity in the brachial valve below the cardinal process.

Type specimen. Holotype, specimen in the British Museum (Natural History) (B.65254). This came from the 'Marlstone' at the base of the Junction Bed between the Middle and Upper Lias, on Thorncombe Beacon, Dorset. It is recorded as 'with *Rh. serrata*', and must therefore have come from the 'P' or 'Px' layer of Jackson (1926).

Distribution. This species is fairly common at the very top of the Middle Lias (*spinatum* zone) on the Dorset coast, and several specimens are preserved from here in the British Museum (Natural History). There are also numerous specimens in Mr. J. F. Jackson's collection from the Dorset coast, now preserved in the National Museum of Wales. A large number of specimens were found by J. F. Walker at the localities he described in inland Dorset (1892); these are also in the British Museum (Natural History). The form was especially common at the top of the Middle Lias in the temporary pit at Shipton Long Lane, near Bothenhampton. A few specimens are known from the same horizon in the Ilminster–South Petherton area of Somerset, but the species is quite unknown elsewhere in Britain.

Dimensions of holotype. Length 27.7 mm., width 26.0 mm., thickness 17.4 mm.

Description. (a) *External characters.* '*Terebratula*' *reversa* is a medium-sized terebratulid, ranging up to about 35 mm. in length, 30 mm. in width and 20 mm. in thickness. It is sub-circular to almost perfectly circular in outline. Both valves are moderately convex, the ventral valve being only slightly more so than the dorsal. After an early globose stage, both valves tend to decrease in convexity so that they meet anteriorly at an acute angle. The anterior commissure varies from rectimarginate to plano-sulcate, the sulcation being wide, flat and low, and often assymmetrical (see Fig. 1). Fold and sinus are barely perceptible. Both valves are smooth, with faint growth-lines. Well-preserved specimens show faint radial capillae.

The beak is small and inconspicuous. It is incurved and usually completely conceals the delthyrium. Beak-ridges are moderately well marked. The pedicle-opening is small, circular and epithyrid.

(b) *Internal characters.* These are very similar to those described by Muir-Wood in *Lobothyris* (1934, pp. 539–40), but for two minor exceptions. Serial sections (see Fig. 2) show the umbonal cavity of the brachial valve extending posteriorly of the plane of articulation, under the trilobed cardinal process. They also reveal the conspicuously punctate pedicle collar, which in this case is not supported by a septum.

Discussion. The species here described shows nearly all the characters given by Dr. Muir-Wood in her emended diagnosis of *Lobothyris*. '*T.*' *reversa* differs from this diagnosis in three ways, (i) the anterior commissure is plano-sulcate in many specimens, (ii) the umbonal cavity extends below the cardinal process, and (iii) no septum has been observed supporting the pedicle collar. The third difference is not considered of importance, since the small septum is often not visible in sections of species of *Lobothyris*. The other differences are more important, but do not, in the author's opinion, justify the erection of a new genus at this stage.

Rectimarginate specimens of '*T.*' *reversa* closely resemble the type species *L. punctata* in external appearance, and can only be distinguished by their

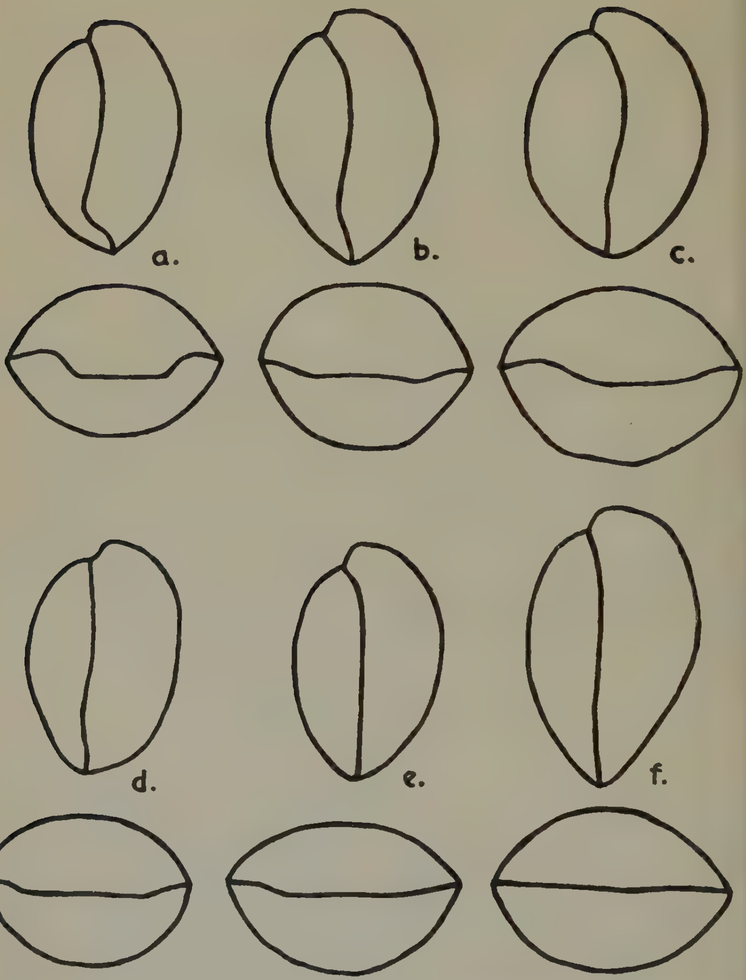


Fig. 1. Camera lucida drawings of six specimens of '*Terebratula*' *reversa* from the *spinatum* zone of Dorset. In each case the top figure shows the lateral view, and the bottom figure the anterior view with the dorsal valve uppermost. The specimens are all in the Walker collection at the British Museum (Natural History), a, BB.13894; b, BB.13893; c, BB.13895; d, BB.13892; e, BB.13896; f, BB.13897. The first four are from Shipton Long Lane, Bothenhampton, near Bridport; the last two are simply labelled 'Chideock'. All × 1·1 approximately

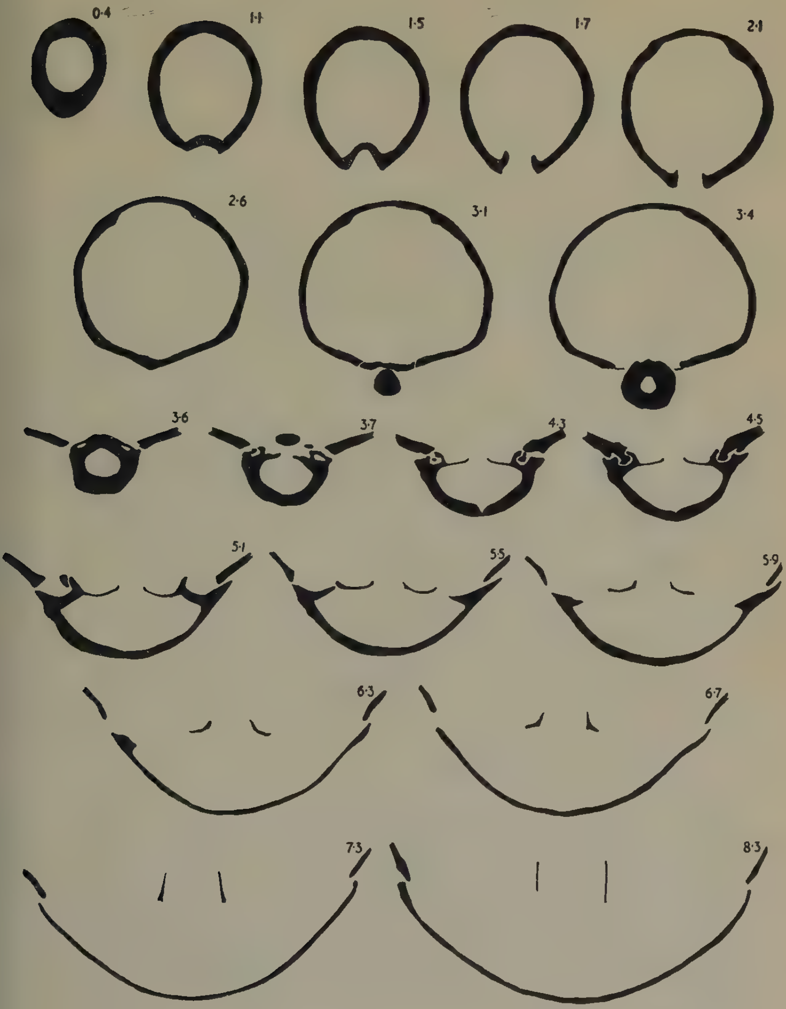


Fig. 2. '*Terebratula*' *reversa* sp. nov. from the top of the Marlstone Rock-bed, Shipton Long Lane, Bothenhampton, Dorset; British Museum (Natural History) (BB.13891). A series of nineteen transverse sections through the posterior part of the shell. The last eleven sections show only part of the pedicle valve. The second, third and fourth sections show the highly punctate pedicle collar. The eighth section shows the umbonal cavity below the cardinal process. The last two sections show the broad plate-like descending branches of the loop. All × 3 approximately

smaller beaks, by their more convex dorsal umbos and by their faint capillation. Muir-Wood has suggested (op. cit., p. 542) that homoeomorphs of *L. punctata* having anterior sulcation may belong to *Euidothyris* or '. . . to a genus apparently homoeomorphous with *Sphaeroidothyris*. . . .' The species under discussion appears to be much closer to *Lobothyris* than to either of the other two named genera, both in external and internal characters.

Several sulcate terebratulid species have been described from the Lias of southern Europe, in the region of the 'Tethys'. Occasional specimens of '*Terebratula*' *radstockiensis* Davidson, from the Lower Lias of south-west England, also show slight sulcation. It is probably significant that the only known sulcate terebratulid in the British Middle Lias only occurs at the southern end of its outcrop. Subsequently a new genus may be erected to include these sulcate forms, but it is as yet far from clear whether '*T.*' *reversa* should correctly be associated with the Tethyan forms. It may well be that plication is partly a function of environment as well as of phylogeny. This is suggested by the fact that there tend to be 'fashions in folding' affecting different families in the same area. The best example of this is probably Dubar's description of multiplication in both Terebratulids and Zeilleriids in the Lias of Morocco (1942). In the Lias of southern Europe, both the above families and the Rhynchonellids include members that are strongly sulcate, though this is highly unusual (at least for the Rhynchonellidae and Terebratulidae) in northern Europe.

'*T.*' *reversa* is almost certainly the form referred to by Buckman (1922, p. 393) as 'somewhat of *Terebratula punctata* style, but anteriorly sulcate, and therefore an inverted form'. It is also the '. . . inverted Terebratulid, gen. et sp. nov.' listed by Buckman from the *spinatum* zone s.s. in Jackson's paper on the Junction Bed (1926, p. 509).

Remarks. The manuscript name '*Inversithyris inversa*' was given by Buckman to the specimen here selected as holotype, when it was in his own collection. This name was never published, but, as has already been stated, it is not considered desirable to erect a new genus until more is known about the other sulcate Liassic terebratulids. The name '*Terebratula*' *reversa* is here proposed, as *T. inversa* would be a homonym of a Quenstedt species.

Family: ZEILLERIIDAE

Genus: **ZEILLERIA** Bayle, 1878

Zeilleria elliotti sp. nov.

Plate 1, Figs. 7 a–c

1878. *Waldheimia mariae* (d'Orbigny); Davidson, p. 158, pl. xxi, fig. 18.
1905. *Waldheimia* cf. *mariae* (d'Orbigny); Rau, pl. iv, fig. 45.

1905. *Waldheimia* cf. *indentata* (Sowerby); Rau, pl. iv, figs. 46–7.
1929. *Terebratula Edwardsi* Davidson; Lanquine, p. 140, pl. ii, fig. 10.

Diagnosis. Small Zeilleriid, about 17 to 25 mm. long, 14 to 21 mm. wide and 15 to 21 mm. thick. Circular to longitudinally oval outline. Almost equally biconvex, both valves strongly inflated. Rectimarginate, no carinae. Strong concentric ornament on unworn specimens. Beak-ridges very sharp and long. Loop long, with blade-like branches, joined by a ventrally-curved transverse band. Dorsal median septum short, terminating abruptly.

Type specimen. Holotype, from Mr. J. F. Jackson's collection, the specimen (being separated from the rest), now in the British Museum (Natural History) (BB.4589). This came from the *paltus* (*serrata*) layer at the top of the *spinatum* zone on Doghus Cliff near Eype on the Dorset coast (see Jackson, 1926).

Distribution. There are a few other specimens in the main part of Mr. Jackson's collection at the National Museum of Wales, and in the British Museum (Natural History). Others were seen in Mr. Jackson's later collections at his home in Charmouth. The species appears to range from the *spinatum* bed proper (Jackson's layer 'R'), through the inter-*paltus*-*spinatum* bed (Jackson's layer 'Px') to the *paltus* (*serrata*) bed (Jackson's layer 'P'). It is also possibly represented by a few doubtful specimens from Jackson's 'At' layer at the base of the Upper Lias. *Z. elliotti* is almost entirely restricted, in Britain, to the Dorset coast sections. Only two specimens have been seen from inland exposures in Somerset.

Dimensions of holotype. Length 18.2 mm., width 14.3 mm., thickness 16.3 mm.

Description. (a) *External characters.* This is a small zeilleriid. None has yet been observed exceeding 25 mm. in length or 21 mm. in width or thickness. In outline it ranges from almost perfectly circular to elliptical about a longitudinal axis. It is also almost exactly elliptical in lateral view due to the strong convexity of both valves. Occasionally the brachial valve is somewhat depressed, but usually the shell is almost equally biconvex. A distinct flattening is observed along the lateral and anterior commissures in many adult specimens, as in *Z. mariae* (d'Orbigny). The anterior commissure is rectimarginate and there are no traces of carinae. In the type specimen a strong concentric ornament is a conspicuous feature on both valves. This has also been observed in several other specimens, but the majority do not show it at all, presumably due to mechanical wear.

The beak is strong and almost erect, with very sharp beak ridges that continue as flanges down the sides of the shell. The pedicle-opening is fairly small, circular, mesothyrid and telate. A wide and high interarea is delimited by the beak-ridges on either side of a wide and low delthyrium. The deltidial plates are sub-rectangular and conjunct.

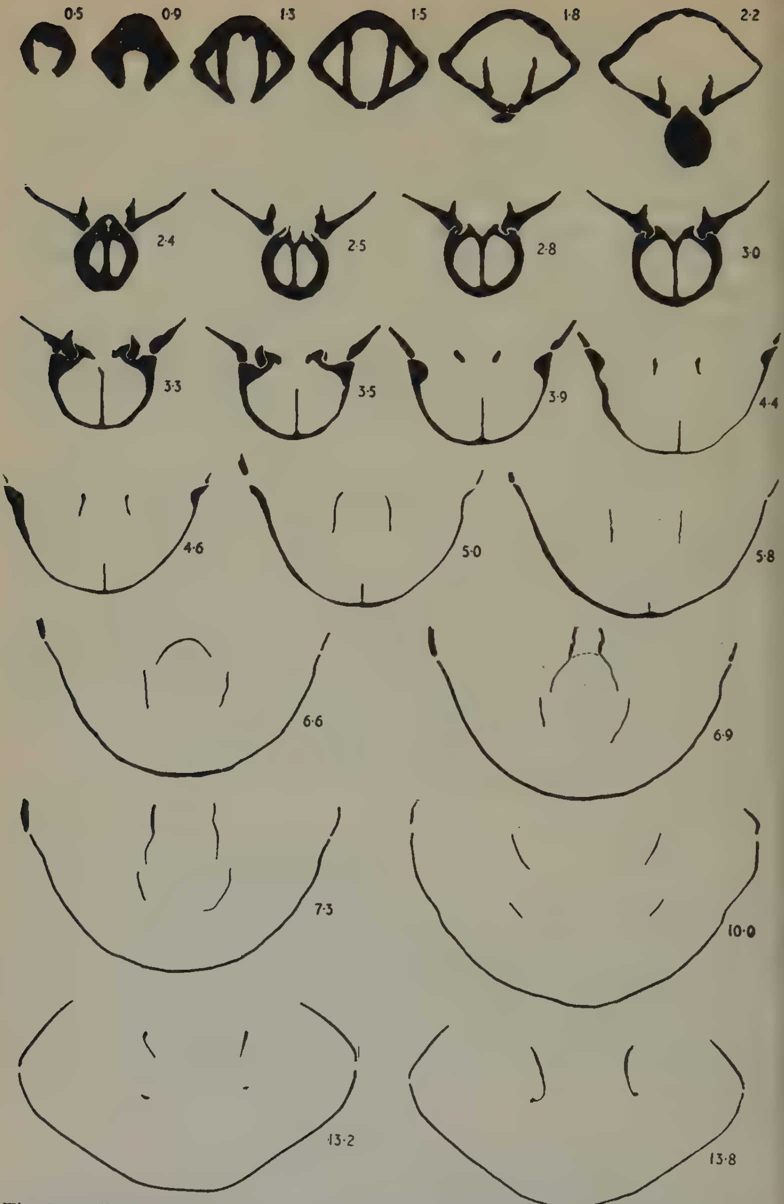


Fig. 3. *Zeilleria elliotti* sp. nov. from the *paltus* layer (*spinatum* zone), Junction Bed, Thorncombe Beacon, Eype, Dorset; author's collection (J.909). A series of twenty-three transverse sections through the shell, all but the first six showing only part of the pedicle valve. The wide septalium is shown in the eighth, ninth and tenth sections. The eighteenth and nineteenth sections show the curved transverse band, whilst the nineteenth and twentieth sections show the ventrally-directed processes from the ascending branches of the loop. All × 3 approximately

(b) *Internal characters.* In the pedicle valve the delthyrial cavity is rectangular in cross-section with a small ventral ridge posteriorly. The lateral umbonal cavities are trigonal in cross-section. Long, almost parallel, dental lamellae can often be seen through the shell. Their leading edges are markedly oblique, so that they could have given little support to the hinge-teeth. These teeth are hook-like and turn inwards slightly. Short, stout denticula are developed laterally.

In the brachial valve there is no clearly defined cardinal process. The median septum is fairly short and terminates abruptly. Usually it can be observed through the shell-wall. The septalium is well developed but shallow. There are strong inner socket-ridges, but these are not differentiated from the hinge-plates. Small dorsally-directed crural bases occur at the distal ends of the hinge-plates. The descending branches of the loop are blade-like and parallel in the dorso-ventral plane. Anteriorly, they become narrower and thread-like, and turn up near the anterior end of the shell. The ascending branches are also blade-like and are joined by a curved, ventrally-directed transverse band. Curious wedge-like, ventrally-directed processes were observed projecting from just below this band in some sections. No muscle-scars were distinguished in either valve. Sections through a typical specimen are shown in Fig. 3; Fig. 4 shows a reconstruction of the brachial valve of this specimen.

Discussion. The holotype is somewhat more globose than average specimens, and is slightly unusual in its well-developed concentric ornament. It is selected because of its exceptionally good preservation. Also it is the specimen referred to by Buckman (in Jackson, 1926, p. 510) as 'A Dallinine. Quite new.' It is certainly not a member of the Dallininae, nor indeed of any of the sub-divisions of the Terebratellacea *sensu stricto*, since its loop is essentially primary, and is in no way connected with the median septum. Here it is provisionally referred to the genus *Zeilleria* pending the publication of Dr. Muir-Wood's work on that genus (see above, p. 1).

The name *Zeilleria* was first used by Bayle (1878) in explanations of plates in his great atlas, but was first described by Douvillé (1879). The species under consideration conforms with all the characters mentioned by Douvillé in his original definition. That is to say, it is rectimarginate, it has dental plates and it has a small beak with sharp beak-ridges. The internal characters of *Zeilleria* were compared by Douvillé (op. cit.) with those of King's invalid genus '*Waldheimia*', but they have not, as yet, been fully described. Muir-Wood (1935, pp. 143–4) described a species, *Z. latifrons* (Krumbeck), from the Upper Jurassic of British Somaliland. She figured a few sections from a poorly-preserved specimen, which, so far as they go, compare reasonably well with those given here for *Z. elliotti*. Later, Muir-Wood described and figured a new species, *Z. wilsfordensis*, from the Middle Jurassic of this country (1939, pp. 481–4, figs. 44–5). Sections through the posterior part of the shell of this species also compare well with those of *Z. elliotti*. In *Z. wilsfordensis*, the hinge-structure was said to be 'nearer to that of *Z. cornuta*' (the type species) ' . . . than to that of the genotypes of *Ornithella* or *Rugitela*' (op. cit., p. 483).

The one point in which *Z. elliotti* can be seen to differ from both *Z. latifrons* and *Z. wilsfordensis* internally is in the relative shallowness of its septalium. Muir-Wood (1935, p. 144) quoted the deep septalium as a distinguishing feature between *Zeilleria* and the Ornithellids, but it appears to the author to be merely a function of the convexity of the posterior part of the brachial valve. *Z. elliotti* differs from *Ornithella* most notably in the absence of shallow depressions separating the inner socket-ridges from the hinge-plates and in the absence of spines on the descending branches of the loop. It differs from *Rugitela* in the shape of the hinge-plates, in the shortness of its median septum and in the rectimarginate nature of its anterior commissure.

Z. elliotti may be distinguished from other Zeillerias by the extremely globose nature of its valves, the absence of carinae and the presence of a strong concentric ornament on some specimens.

Remarks. The specific name is given as a tribute to Mr. G. F. Elliott, in recognition of the numerous valuable and thought-provoking papers he has written on the long-looped terebratuloids.

EXPLANATION OF PLATE

All the specimens are reproduced at approximately one and a third times natural size. In each case (a) is the dorsal view, (b) the lateral view and (c) the anterior view. BM = British Museum (Natural History), GSM = Geological Survey Museum, DVA = author's collection [later to be presented to the British Museum (Natural History)]. Fig. 7 was photographed by Mr. J. V. Brown; all the others were photographed by the author after treatment with ammonium chloride. The register numbers are given in parentheses.

Fig. 1. *Lobothyris punctata clevelandensis* subsp. nov. BM (B.32486). Holotype. Middle Lias (*spinatum* zone), Eston Mine, Cleveland, Yorkshire.

Fig. 2. *Lobothyris punctata clevelandensis* subsp. nov. DVA (J.510/4). Paratype 1. Marlstone Rock-bed, Middle Lias (*spinatum* zone), old ironstone working, East Adderbury, near Banbury, Oxfordshire (map reference SP 485354).

Fig. 3. *Lobothyris punctata clevelandensis* subsp. nov. DVA (J.1002/2). Paratype 2. Loose block, Middle Lias sandstone (*margaritatus* zone), Huntcliff, near Saltburn, Yorkshire.

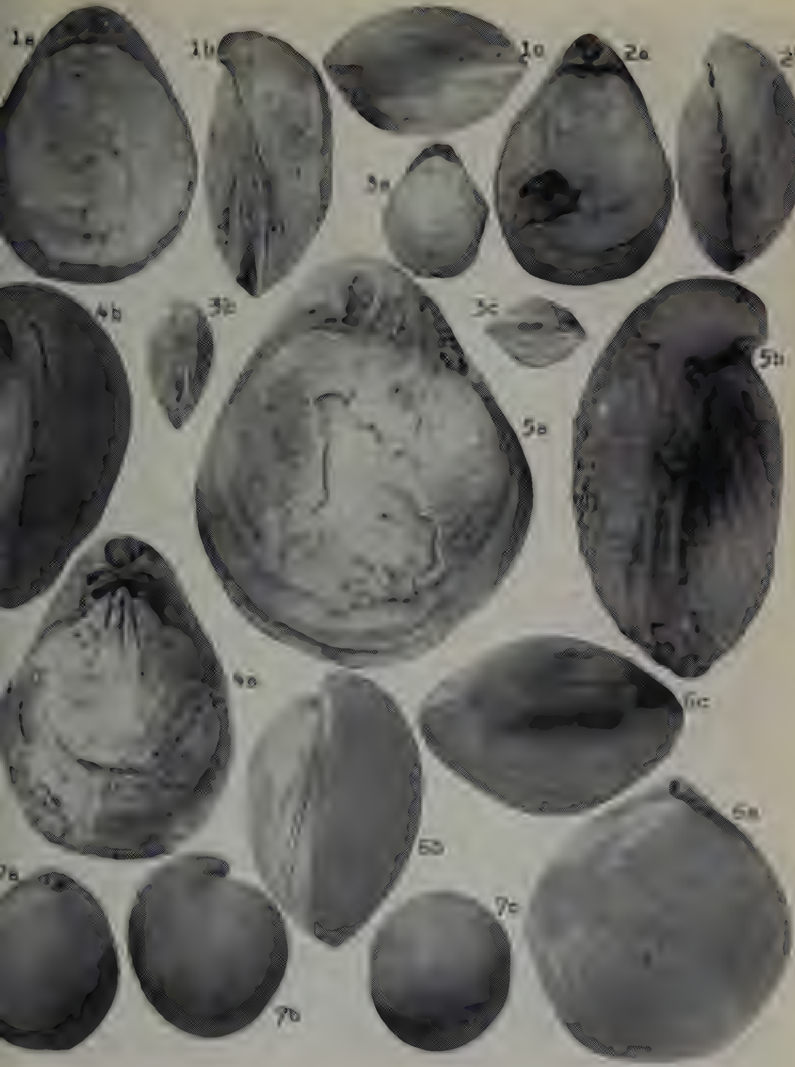
Fig. 4. *Lobothyris punctata clevelandensis* subsp. nov. BM (47247). Paratype 3. Middle Lias, almost certainly from Staithes, Yorkshire. A natural internal mould showing muscle-scars.

Fig. 5. *Lobothyris punctata clevelandensis* subsp. nov. GSM (26374). Paratype 4. Upper Lias (*jurense* zone, *moorei* sub-zone), Blea Wyke, Yorkshire.

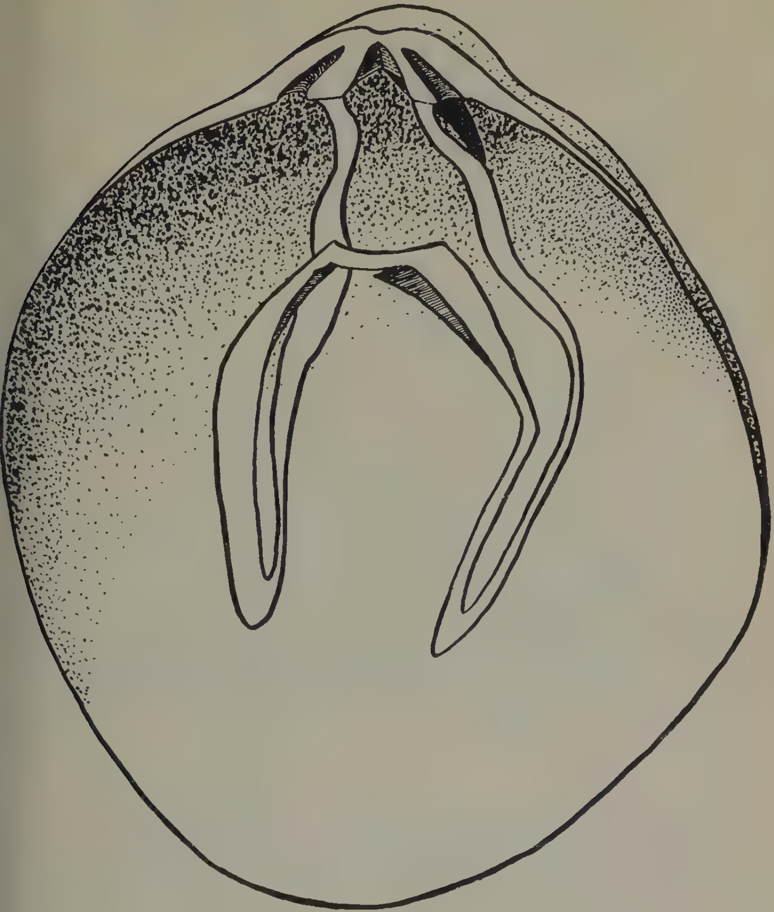
Fig. 6. '*Terebratula*' *reversa* sp. nov. BM (B.65254). Holotype. Middle Lias (*spinatum* zone), Jackson's 'P' or 'Px' layer, Thorncombe Beacon, near Eype, Dorset.

Fig. 7. *Zeilleria elliotti* sp. nov. BM (BB.64589). Holotype (mentioned Buckman, in Jackson, 1926, p. 510, as 'A Dallinine. Quite new'). Middle Lias (*spinatum* zone), Jackson's 'P' layer, Doghus Cliff, near Eype, Dorset.

PLATE 1



[*To face p.* 12



ig. 4. *Zeilleria elliotti* sp. nov. Reconstruction of the brachial valve, founded on the ansverse sections shown in Fig. 3, together with other intermediate sections. Note-orthy features are the short median septum (shown in black) and the form of the ng loop with its unusual ventrally-directed processes below the transverse band. pproximately × 7

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Fish Otoliths from the London Clay of Bognor Regis, Sussex

by F. C. STINTON

Received 15 October 1954

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ABSTRACT: The paper consists of systematic descriptions of otoliths from the London Clay of Bognor Regis. Seven new species are recorded and certain earlier naccurate determinations corrected.

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1. INTRODUCTION

N THE ABSENCE of entire teleostean remains in our Tertiary strata the palaeontologist experiences some difficulty about compiling faunal lists of this widely represented class of fishes. The usual remains consist of isolated teeth, fin-spines and vertebrae, all of which are practically indeterminable. However, in addition to these remains there occur numerous fish otoliths or ear-stones at most horizons of the Eocene and Oligocene strata. These objects show generic characters which may be utilised for accurate determinations by comparing the fossil forms with otoliths from corresponding living genera.

As the determination of the fossil forms requires access to a comprehensive series of otoliths from all the genera of living fishes of the world, I have endeavoured to assemble a working series of the living forms for this purpose. Although I now have representative otoliths from over 450 genera these form only a small proportion of the total necessary for the dentification of all specimens. However, it has been possible to make generic determinations of most of the new species described below, while those which could not be matched accurately with corresponding extant genera have been assigned to the appropriate family or group. It is to be hoped that further Recent otoliths will come to hand at a later date so that all the specimens may be assigned to their proper genera. In addition, certain errors of determination which occur in earlier works have been corrected and it should be emphasised that these errors were mainly the result of lack of Recent material for comparative purposes. In some instances, errors in the very early works on the subject have been perpetuated to recent times, and other mistakes have occurred because the figures given were of worn examples of species already described under other names.

The otoliths to be described were not collected *in situ*, but were obtained as foreshore accumulations occurring at low tide. Although it should be possible to obtain such specimens *in situ* the opportunities for so doing are rarely available as collecting may only be carried out during spring tides and the otoliths appear to be too widely separated to be obtained even in moderate numbers. The assiduous collecting of Messrs. E. M. Venables and H. E. Taylor has resulted in numerous specimens coming to light, representing twenty genera of teleosteans. They include seven new species.

As a guide to the determinative features of an otolith the following figure may assist in clarifying the terms used in the study of these objects.

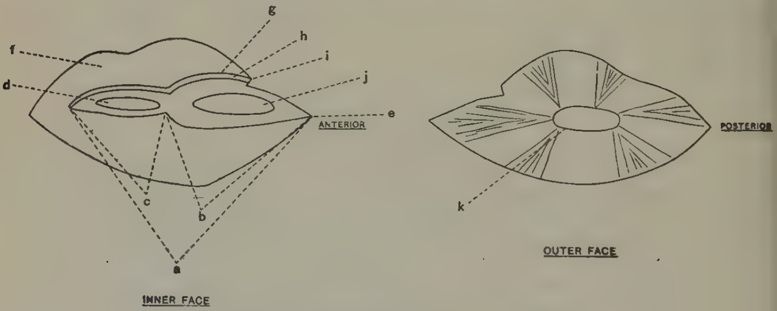


Fig. 1. Diagram of parts of an otolith

Key

a Sulcus
b Ostium
c Cauda
d, j Colliculi
e Rostrum
f Area
g Crista superior
h Exisura ostii
i Antirostrum
k Umbo

2. SYSTEMATIC DESCRIPTIONS

Order: *ISOSPONDYLI*

Suborder: *CLUPEOIDEA*

Family: PTEROTHRISSIDAE Hilgendorf, 1877

Genus: **PTEROTHRISSUS** Hilgendorf, 1877

Pterothrissus Hilgendorf, 1877. *Leopoldina*, **13** (15–16), 127.

Pterothrissus umbonatus (Koken)

Plate 2, Figs. 1, 2

1884. *Ot. inc. sedis umbonatus* Koken, E., *Z. deutsch. geol. Ges.*, **36,** 557, pl. 12, fig. 12.
1888. *Ot. inc. sedis aff. umbonatus* Koken, E., *Z. deutsch. geol. Ges.*, **40,** 294, pl. 17, fig. 12a.
1891. *Ot. inc. sedis conchaeformis* Koken, E., *Z. deutsch. geol. Ges.*, **43,** 135, text-fig. 22.
Ot. inc. sedis robustus Koken, E., *Z. deutsch. geol. Ges.*, **43,** 136–7, text-fig. 25.
Ot. inc. sedis lunaburgensis Koken, E., *Z. deutsch. geol. Ges.*, **43,** 137, text-fig. 26.
1893. *Ot. inc. sedis bellus* Procházka, V. J., *Rozpr. české Akad.*, (2), **2,** c.24, 64, pl. 3, fig. 9 a, b.
1906. *Ot. inc. sedis lunaburgensis* Koken, in Schubert, R. J., *Jb. geol. Reichsanst.*, **56,** 676, pl. 17 (4), fig. 33.
1906. *Ot.* (*? Dentex*) *dubius* Priem, F., *Bull. Soc. géol. Fr.*, (4), **6,** 268, figs. 9, 10.
1908. *Ot.* (*? Dentex*) *dubius* Priem, F., *Ann. Paléont.*, 102.
1910. *Ot. inc. sedis umbonatus mut. rupeliensis* Leriche, M., *Mém. Mus. Hist. nat. Belg.*, **5,** 353, text-figs. 153–6 b.
1911. *Ot.* (*? Dentex*) *dubius* Priem, F., *Ann. Paléont.*, **6,** 23.
1915. *Ot.* (*Dentex*) *aff. nobilis ?* Koken, in Priem, F., *Bull. Soc. géol. Fr.*, **14,** 263, text-fig. 42.
1916. *Ot.* (*Beryx ?*) *bartonensis* Schubert, R. J., *Jb. geol. Reichsanst.*, **65,** 279, pl. 7, figs. 18–20.
1916. *Ot. inc. sedis umbonatus* Koken, in Shepherd, C. E., *Knowledge*, (n.s.), **13,** 183, fig. 155 (8).
1919. *Ot. inc. sedis lunaburgensis* Koken, in Pieragnoli, L., *Riv. ital. Paleont.*, **25,** 37, pl. 2, figs. 32 a, b.
1923. *Dentex* (*?*) *dubius* Priem, in Leriche, M., *Bull. Soc. géol. Fr.*, (4), **22,** 197.
1924. *Non Ot. inc. sedis umbonatus* Koken, in Frost, G. A., 1924. *Trans. N.Z. Inst.*, **55,** 613, pl. 62, fig. 19.
1925. *Ot. inc. sedis umbonatus* Koken, in Frost, G. A., *Ann. Mag. nat. Hist.*, (9), **16,** 164, pl. 10, fig. 9.
1931. *O.* (*incert. sed.*) *umbonatus* Koken, in Chaine, J. & Duvergier, J., *Mem. Inst. Catalana Hist. Nat.*, **3,** 37.
1933. *Ot.* (*Berycidarum*) *bartonensis* Schubert, in Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **12,** 395, pl. 12, fig. 21.
1946. *Dentex* (*?*) *dubius* Priem, in Casier, E., *Mém. Mus. Hist. nat. Belg.*, **104,** 136, pl. 3, fig. 15 a, b.

Dimensions. Length 10.07 mm., width 7.00 mm. (Fig. 1).

Diagnosis. A thick, biconvex, roughly rectangular, left sagitta otolith. All the rims are slightly rounded and entire. Dorsal rim notched towards the posterior rim. Outer face smooth with an oblique sulcus opening widely on the anterior rim. The sulcus consists of a wide, shallow ostium which is sharply differentiated from the straight, narrow cauda. No rostrum or antirostrum. There is a shallow depression above the crista superior. No colliculi.

Fig. 2 shows an unabraded, juvenile sagitta otolith of the same species, from the Lower Barton Beds, Highcliffe, Hants. In this specimen the outer face shows marked radial ribbing from the dorsal to the outer rims, while the otolith is more oval in shape. The rims also show denticulations. As the fish approaches maturity the deposition of successive layers of calcareous matter thickens the otolith, making it more rectangular while the ornamentation of the outer face is lost. The diverse shapes of the adult otolith have resulted in a series of specific names, while the various incorrect generic determinations made in the past have presumably been due to lack of Recent otoliths for comparison. Also it should be noted that some of the specimens previously described have been subjected to a considerable degree of attrition which has markedly altered their original shapes.

Comparison of this specimen with otoliths from the Recent *Pterothrissus belloci* Cadenat shows a marked similarity between the two forms and leaves no doubt about the correctness of assigning the fossil form to this genus.

It has not been possible to compare this specimen with the holotype or syntypes described by the various continental authors, so that it has been necessary to rely on the figures given.

This species occurs throughout the Eocene, Oligocene and Miocene. It is rare at Bognor but is common at some horizons in the Bracklesham and Barton Series.

Order: *APODES*

Family: CONGRIDAE

Genus: **CONGER** Cuvier, 1829

1829. Cuvier, *Règne Anim.*, vol. II, p. 350.

Conger acutus n.sp.

Plate 2, Fig. 3

Dimensions of Holotype. Length 7.54 mm., width 4.00 mm.

Diagnosis. A typical biconvex, right sagitta otolith of the Congridae. Outer face smooth; rounded dorsal, ventral and anterior rims; produced posteriorly to a rounded point. Inner face smooth with the sulcus opening on the anterior rim. The sulcus consists of a very short ostium and a relatively long, narrow, oblique cauda which is bulbous at its extremity. No rostrum, antirostrum or colliculi. A shallow depression above the crista superior.

The sulcus in this specimen compares exactly with that of an otolith from the living *Conger vulgaris* Cuvier, but the fossil form is narrower and more regular in its outline.

The holotype is the only known specimen.

Genus: **UROCONGER** Kaup, 1856

1856. *Kaup, Cat. Apod. Fish.*, p. 110.

Uroconger minimus (Frost)

Plate 2, Fig. 4

1933. *Ot.* (*Muraenesox*) *minimus* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **12**, 393, pl. 12, fig. 16.

Dimensions. Length 4.50 mm., width 2.45 mm.

Diagnosis. A biconvex, left sagitta otolith of oval shape, pointed anteriorly. Rims regularly rounded. Smooth outer and inner faces with no ornamentation. A narrow sulcus opening on the anterior rim. Ostium very short and shallow; a relatively long, narrow cauda extending diagonally across the inner face but not reaching the posterior rim. No rostrum or antirostrum. A shallow, oval depression on the upper area above the crista superior.

Frost's holotype is a very waterworn example which has lost most of its determinative features. In particular it lacks the vertical groove from the posterior end of the cauda to the dorsal rim which is seen in the otoliths from extant species of *Muraenesox* such as *M. cinereus* Forsk. and *M. talabon* Cantor. In the character of its sulcus, with the oval depression above it, it closely resembled the otoliths from the living *Uroconger lepturus* Kaup, but the fossil form is more spherical in outline.

Order: *ANACANTHINI*

Family: MERLUCCIIDAE

Genus: **MERLUCCIUS** Rafinesque, 1810

1810. Rafinesque, *Carrat. di Alc. Nuovi Gen.*, etc., 25.

? **Merluccius shepherdi** Schubert

1915. *Ot.* (*Merluccius*) *shepherdi* Schubert, R. J., *Jb. geol. Reichsanst.*, **65**, 282, pl. 7, figs. 25–8.

1934. *Ot.* (*Merluccius*) *shepherdi* Schubert, in Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **14**, 502, pl. 14, figs. 6, 7.

A fragment of a typical *Merluccius* otolith.

It appears to be identical with that of *M. shepherdi* Schubert, but is too ncomplete for specific determination.

Family: GADIDAE

Genus: **GADUS** (Artedi) Linnaeus, 1758

1758. (Artedi) Linnaeus, *Syst. Nat.*, ed. X, 251.

Gadus subnotus Frost

Plate 2, Fig. 5

1934. *Ot.* (*Gadus*) *subnotus* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **14**, 500, pl. 14, fig. 1.

Dimensions. Length 4.88 mm., width 2.7 mm.

Diagnosis. A thick, biconvex, left sagitta otolith, pointed posteriorly. Rounded dorsal and ventral rims, rounded anterior rim. Outer face ornamented with tuberculations. Inner face flat and nearly smooth. Sulcus completely enclosed, divided into ostium and cauda of equal length by a central constriction. Colliculi almost completely fill the sulcus.

This otolith shows a marked similarity to that of the living *Gadus luscus* Lin., but the fossil form shows a much more marked constriction of the sulcus than in the living form which has the cauda and ostium separated by a diagonal line instead of a central constriction.

This species occurs frequently at Bognor and also at most other London Clay exposures.

Genus: **RANICEPS** Cuvier, 1829

1829. Cuvier, *Règne Anim.*, vol. II, p. 336.

Raniceps planus Koken

Plate 2, Fig. 6

1891. *Ot.* (*Raniceps*) *planus* Koken, E., *Z. deutsch. geol. Ges.*, **43**, 87, pl. 3, figs. 7, 7a.

Dimensions. Length 4.38 mm., width 2.53 mm.

Diagnosis. A thick, biconvex, right sagitta otolith, pointed anteriorly. Dorsal, ventral and posterior rims scalloped. Outer face ornamented with radiating ridges from the centre to the rims. Sulcus on inner face completely enclosed, somewhat undulating and pointed at both ends. It is divided into ostium and cauda by a marked constriction of both crista superior and inferior, the ostium being longer than the cauda. Sulcus almost filled with colliculi. There are rather prominent ribs running from both rims of the sulcus to the dorsal, ventral and posterior rims.

This otolith appears to agree exactly with Koken's figures, both in the general outline and the character of the sulcus.

It occurs rarely at Bognor, only three specimens having been found so far.

Order: *BERYCOMORPHI*

Family: MONOCENTRIDAE

Genus: **MONOCENTRIS** Bloch & Schneider, 1801

1801. Bloch & Schneider, *Syst. Ichthyol.*, p. 100.

Monocentris lemoinei (Priem)

Plate 2, Fig. 7

1906. *Ot.* (*Sparidarum*) *lemoinei* Priem, F., *Bull. Soc. géol. Fr.*, (4), **6**, 273–4, text-figs. 34, 35.

1909. *Monocentris lemoinei* Priem, in Leriche, M., *Ann. Soc. Géol. Nord*, **37**, 246–7, pl. 6, figs. 7, 8.
1916. *Ot.* (*Apogonidarum*) *circularis* Shepherd, C. E., *Knowledge*, (n.s.,) **13**, 183, fig. 154 (3 a, b).
1925. *Ot.* (*Monocentris*) *lemoinei* Priem, in Frost, G. A., *Ann. Mag. nat. Hist.*, (9), **16**, 162, pl. 10, fig. 6.
1933. *Ot.* (*Polymixia*) *eocenicus* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **12**, 394, pl. 12, fig. 20.

Dimensions. Length 5.70 mm., width 4.38 mm.

Diagnosis. A flat, circular, left sagitta otolith. Outer face flat and smooth. Inner face smooth. Dorsal, ventral and posterior rims rounded; anterior rim notched. Sulcus opening widely on the anterior rim. It consists of a wide, shallow, subcircular ostium separated from the nearly straight, narrow cauda by a markedly lower angle. The cauda is pointed at its extremity and does not reach the posterior rim. Slight rostrum, marked antirostrum and excisura. No colliculi. A depression above the crista superior.

This specimen closely resembles the otoliths of the living *Monocentris japonica* Bloch & Schneider, but differs in the posterior notch. It differs from the otoliths of the living *Polymixia* in outline and in the character of the sulcus.

This species occurs frequently at Bognor.

Order: *PERCOMORPHI*

Group: Percoidei

Family: AMMODYTIDAE

Genus: **AMMODYTES** (Artedi) Linnaeus, 1758

1758. (Artedi) Linnaeus, *Syst. Nat.*, ed. X, p. 247.

Ammodytes pseudoacuminatus (Šulc)

Plate 2, Fig. 8

1891. *Non. Ot.* (*Pleuronectidarum*) *acuminatum* Koken, E., *Z. deutsch. geol. Ges.*, **43**, 107, pl. 5, fig. 12.
1906. *Ot.* (*Pleuronectidarum*) *acuminatus* Koken, in Bassoli, G. G., *Riv. ital. Paleont.*, **12**, 47, pl. 2, figs. 5, 6.
1932. *Uranoscopus pseudoacuminatus* Šulc, J., *Rozp. geol. Úst. čsl.*, **7**, 78, pl. 2, figs. 5–7.

Dimensions. Length 3.81 mm., width 1.85 mm.

Diagnosis. A spherical, biconvex, right sagitta otolith. Dorsal and ventral rims regularly rounded; pointed posteriorly and anteriorly. Outer and inner faces smooth. Sulcus consisting of a prominent, spherical depression, centrally situated, with a very shallow, narrow channel to the anterior rim, the latter feature being often lost in waterworn examples.

This specimen shows little resemblance to that figured by Koken as *P.*

acuminatus and has none of the pleuronectid characteristics such as a flat, circular outline and undulating sulcus. Neither does this specimen compare with otoliths from the extant species *Uranoscopus scaber* Lin., *Uranoscopus bufo* Val., or *Uranoscopus archionema* Regan, which are all more oval in outline while the sulcus is quite different. However, the fossil form shows a marked similarity to the otoliths of the living *Ammodytes tobianus* (Art.) Lin., differing only in its somewhat deeper sulcus.

This species occurs commonly at Bognor where it forms approximately thirty per cent of the otolith assemblage. It is also frequent at most of the other London Clay exposures in this country.

Family: SERRANIDAE (s.l.)

In this family are placed several specimens which, although not referable to the genus *Serranus*, are Percoid forms which may be provisionally assigned to this family in its wide sense. Absence of comparable extant forms prevents their generic determination at present.

Otolithus (Serranidarum) undulatus n.sp.

Plate 2, Fig. 9

Dimensions of Holotype. Length 3.80 mm., width 2.27 mm.

Diagnosis. A right sagitta otolith. Rounded ventral rim; notched posterior rim, slightly undulating dorsal rim; short, oblique anterior rim. Outer face concave and irregularly ridged on the dorsal half. Inner face convex. Sulcus consisting of a wide, shallow, oblique ostium opening widely on the anterior rim and a short, straight, horizontal cauda, the two being separated by rounded upper and lower angles. Marked rostrum, antirostrum and excisura present. No colliculi. A depression above the crista superior and a raised semicircular platform below the sulcus.

The holotype is the only known specimen at present.

Otolithus (Serranidarum) minsterensis Frost

Plate 2, Fig. 10

1934. *Ot.* (*Serranidarum*) *minsterensis* Frost, G. A., *Ann. Mag. nat. Hist.*, (10) **13**, 384, pl. 14, fig. 13.

Dimensions. Length 3.86 mm., width 2.70 mm.

Diagnosis. A left sagitta otolith of oval outline. Dorsal and posterior rims feebly undulating; ventral rim rounded; oblique anterior rim. Outer face concave and irregularly ridged. Smooth, convex inner face. Slightly undulating sulcus which opens widely on the anterior rim and extends horizontally across the inner face, turning down slightly at its extremity. Sulcus consisting of a roughly triangular ostium separated from the cauda by a small constriction. Rostrum, antirostrum and excisura present. No colliculi. A shallow depression above the crista superior, accentuating it.

This species is not uncommon at Bognor.

Genus: **EPINEPHELUS** Bloch, 1793

1793. Bloch, *Naturg. der ausland. Fische*, vol. 7, p. 11.

Epinephelus ovalis n.sp.

Plate 2, Fig. 11

Dimensions of Holotype. Length 5.15 mm., width 2.89 mm.

Diagnosis. An oval, right sagitta otolith. All rims regularly rounded. Outer face concave, ornamented with indistinct ribbing which is more or less vertical. Convex, smooth inner face. Sulcus undulating, opening narrowly on the anterior rim. Ostium and cauda of approximately equal length, separated by a central constriction of the sulcus. A slight rostrum and antirostrum. No colliculi. A shallow depression above the central constriction on the crista superior.

A marked similarity is seen between this form and the otoliths of various species of *Epinephelus* such as *E. alexandrinus* Cuv. et Val., *E. boenack* Bloch, etc., the sulcus being almost identical in each case but the general outline of the fossil form is more regular and oval in shape. This form may, without doubt, be assigned to the genus *Epinephelus*.

Family: APOGONIDAE

Genus: **APOGON** Lacépède, 1802

1802. Lacépède, *Hist. Nat. Poiss.*, **3,** 411.

Apogon bellovacinus (Priem)

Plate 2, Fig. 12

1911. *Ot.* (*Monocentris*) *bellovacinus* Priem, F., *Ann. Paléont.*, **6,** 27, text-figs. 21–3.

1916. *Ot.* (*Monocentris?*) *bellovacinus* Priem, in Schubert, R. J., *Jb. geol. Reichsanst.*, **65,** 279, pl. 7, figs. 1–6.

1916. *Ot.* (*Monocentris ?*) *bellivicianus* Shepherd C. E., *Knowledge*, (n.s.), **13,** 183, fig. 154 (1).

Ot. (*Monocentris ?*) *leridei* Shepherd, C. E., *Knowledge*, (n.s.), **13,** 183, fig. 154 (2).

Non. Ot. (*Apogonidarum*) *eocenicus* Shepherd, C. E., *Knowledge*, (n.s.), **13,** 183, fig. 154 (4).

922. *Ot.* (*Monocentris ?*) *bellovacinus* Priem = *Ot.* (*Apogon*) *eocenicus* Shepherd, in Shepherd, C. E., *Bull. Soc. géol. Fr.*, (4), **22,** 139, pl. 7, fig. 3.

934. *Ot.* (*Apogon*) *eocenicus* Shepherd, in Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **13,** 429, pl. 15, fig. 10.

Ot. (*Apogon*) *tuberculatus* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **13,** 430, pl. 15, fig. 11.

Dimensions. Length 3.03 mm. (incomplete), width 2.51 mm.

Diagnosis. A right sagitta otolith. Outer face slightly convex; a central umbo with radiating ridges to the rims. All rims rounded. Sulcus on inner face straight, consisting of a wide, oval ostium opening widely on the anterior rim and a narrow cauda of the same length as the ostium. The cauda does not reach the posterior rim. A marked upper angle at the junction of ostium and cauda. A spherical depression above the crista superior.

In young, unabraded specimens the outer face is strongly tuberculated over its entire area, but this feature is lost in more mature otoliths while attrition is responsible for the completely smooth outer faces which predominate among adult forms. The presence of tuberculations on the outer face cannot be considered as a specific feature and certainly does not justify placing the smooth and tuberculated forms in two distinct species.

Complete specimens of this species from other London Clay exposures at Sheppey, Tolworth, etc., show antirostrum, rostrum and excisura.

This species occurs rarely in the London Clay but is exceedingly common at some horizons of the Bracklesham and Barton series.

Family: CENTROPOMIDAE

Genus: **CENTROPOMUS** Lacépède, 1802

1802. Lacépède, *Hist. Nat. Poiss.*, IV, 248.

Centropomus superpendens Frost

Plate 2, Fig. 13

1934. *Ot.* (*Centropomus*) *superpendens* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **13,** 426, pl. 15, fig. 3.

Dimensions. Length 5.30 mm., width 3.10 mm.

Diagnosis. A right sagitta otolith. Rounded ventral rim, slightly rounded dorsal rim, oblique anterior and posterior rims. Outer face concave, irregularly thickened on the dorsal rim, with a central umbo. Inner face smooth with a horizontal sulcus which opens widely on the anterior rim and does not reach the posterior rim. Sulcus consisting of an oval, shallow, short ostium and a long, narrower cauda which turns down somewhat at its extremity, running parallel with the posterior rim. Broad rostrum, no antirostrum. No colliculi. Ostium and cauda separated by upper and lower angles. A shallow depression above the crista superior.

The sulcus of this specimen compared closely with that of the living *Centropomus undecimalis* Cuv. et Val., but the general outline of the otolith is narrower than in the otolith of the living form.

Genus: **PSAMMOPERCA** Richardson, 1848

1848. Richardson, *Zoology*, *Erebus & Terror*, *Fish*, p. 115.

Psammoperca sheppeyensis (Frost)

Plate 2, Fig. 14

1934. *Ot.* (*Sciaenidarum*) *sheppeyensis* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **13**, 427, pl. 15, fig. 4.

Dimensions. Length 9.23 mm., width 4.31 mm.

Diagnosis. A thickened, left sagitta otolith. Outer face concave and smooth. Low dorsal and rounded ventral rims. Pointed posteriorly; oblique anterior rim. Convex, smooth inner face. A long sulcus opening on the anterior rim and not quite reaching the posterior rim at its turned-down extremity. The sulcus consists of a long, rather narrow, parallel-sided ostium and a narrower, slightly curved cauda, the two being separated by a central constriction. No antirostrum or colliculi. A broad rostrum.

This typically Percoid otolith has none of the features of the otoliths of the Sciaenid group, all of which have a very wide, oval ostium and a strongly curved cauda. The sulcus in the fossil form closely resembles that of otoliths from the living *Psammoperca waigensis* Cuv. et Val. and this specimen should be assigned to the genus *Psammoperca*.

Family: LUTIANIDAE

Subfamily: LUTIANINAE

Genus: **CAESIO** Lacépède, 1802

1802. Lacépède, *Hist. Nat. Poiss.*, III, p. 85.

Caesio bognoriensis n.sp.

Plate 2, Fig. 15

Dimensions of Holotype. Length 5.26 mm., width 2.99 mm.

Diagnosis. A thin, right sagitta otolith. Concave outer face showing indistinct ribbing and concentric growth lines. Dorsal and ventral rims rounded; posterior rim notched; oblique anterior rim. Inner face convex. Sulcus opening narrowly on the anterior rim and extending horizontally but not reaching the posterior rim. It is slightly bulbous and depressed at its extremity. Sulcus consisting of a rather narrow, deep ostium separated from the shallower cauda by a marked constriction. There is a narrow groove from the end of the cauda to the posterior rim. Slight rostrum and antirostrum. No colliculi. The upper half of the inner face is faintly ornamented with radiating ridges to the dorsal rim.

The sulcus of this specimen compares well with otoliths from the extant species *Caesio chrysozona* (K. v H.) Cuv. et Val. and *C. erythrogaster* (K. v H.) Cuv. et Val., but the living forms are markedly more concave. The fossil form is tentatively assigned to this genus.

Family: POMADASYIDAE

Genus: **POMADASYS** Lacépède, 1802

1802. Lacépède, *Hist. Nat. Poiss.*, IV, p. 515.

Pomadasys ovalis n.sp.

Plate 2, Fig. 16

Dimensions of Holotype. Length 4.76 mm., width 2.73 mm.

Diagnosis. A left sagitta otolith. Outer face concave, ornamented with a central, longitudinal ridge and irregular ribbing from it to the dorsal and ventral rims. Rounded dorsal and ventral rims; otolith pointed posteriorly and anteriorly. Inner face convex and smooth. Sulcus on inner face opening narrowly on anterior rim and extending horizontally across the otolith but not reaching the posterior rim. Sulcus somewhat arched, consisting of a rather short, parallel-sided ostium and a long, narrow cauda which is separated from the ostium by upper and lower angles. Cauda pointed at its extremity. Slight rostrum, no antirostrum or colliculi.

Comparison with living species of *Pomadasys*, e.g. *P. argyreus* Cuv. et Val. and *P. hasta* Bloch, shows the sulcus to be almost identical in each case except that the cauda is somewhat more curved in the extant forms. The comparative features are sufficiently exact to place the fossil form in the above genus.

Family: SPARIDAE

Genus: **DENTEX** Cuvier, 1817

1817. Cuvier, *Règne Anim.*, ed. 1, p. 272.

Dentex pentagonalis n.sp.

Plate 2, Fig. 17

Dimensions of Holotype. Length 8.45 mm., width 5.63 mm.

Diagnosis. A large, right sagitta otolith of roughly pentagonal shape. Outer face concave, ornamented with irregular ridges showing concentric scalloping, which radiate from the centre of the otolith to all the rims. Dorsal and posterior rims feebly scalloped; ventral rim regularly rounded; anterior rim oblique. Inner face convex. Horizontal sulcus opening widely on the anterior rim with a wide, shallow ostium which is separated from the narrower cauda by a prominent lower angle and a rounded upper angle. Cauda depressed somewhat at its extremity and not reaching the posterior rim. Slight rostrum, antirostrum and excisura. A shallow depression above the crista superior.

This otolith compares very closely with those of the extant species *Dentex filosus* Val., the sulcus being identical in each case but the general outlines differ, that of the living form being prominently denticulated on the dorsal and posterior rims.

The holotype is the only known specimen to date.

Suborder: *HOLCONOTI*

Family: EMBIOTOCIDAE

Genus: **DITREMA** Temminck & Schlegel, 1844

1844. Temminck & Schlegel, in Siebold, *Faun. Japon.* (*Pisc.*), 77.

Ditrema sheppeyensis Frost

Plate 2, Fig. 18

1934. *Ot.* (*Ditrema*) *sheppeyensis* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **13**, 383, pl. 14, fig. 10.

Dimensions. Length 4.61 mm., width 3.02 mm.

Diagnosis. A left sagitta otolith. Outer face concave, ornamented with radiating ribbing to the dorsal and posterior rims. No central umbo. Dorsal and posterior rims denticulated, rounded ventral rim, oblique anterior rim. Sulcus opening on anterior rim, consisting of a subcircular ostium and a narrower, slightly undulating cauda which is somewhat depressed at its extremity. Ostium and cauda separated by lower angle and rounded upper angle. Marked rostrum, slight antirostrum and excisura present. No colliculi. Faint radiating ridges from the crista superior to the dorsal rim.

This species was described by Frost from the London Clay, Isle of Sheppey. It occurs rarely at Bognor.

Group: OPHIDIOIDEI

Family: OPHIDIIDAE

The following three species undoubtedly belong in this family but lack of suitable comparative material prevents their generic determination at present.

Otolithus (Ophidiidarum) productus n.sp.

Plate 2, Fig. 19

Dimensions of Holotype: Length 5.70 mm., width 3.02 mm.

Diagnosis. A thickened, biconvex, right sagitta otolith, pointed pos-eriorly with rounded ventral and anterior rims; nearly straight dorsal rim. Outer face smooth. Inner face smooth and nearly flat. Sulcus enclosed, consisting of a rather wide, spherical depression, the ostium, and a small depressed cauda which is sharply delineated from the ostium by a marked ower angle. No colliculi.

This otolith differs from the other species described in its general outline and relatively larger sulcus. It has some affinity with *O. waltoni* Schubert, but is more produced posteriorly, has no colliculi and has no anterior projection on the dorsal rim.

Otolithus (Ophidiidarum) sheppeyensis Frost

Plate 2, Figs. 20, 21, 22

1934. *Ot.* (*Ophidiidarum*) *sheppeyensis* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **14**, 444, pl. 12, figs. 9–11.

Dimensions Fig. 20: Length 4.07 mm., width 2.83 mm.
Fig. 21: Length 3.95 mm., width 2.51 mm.
Fig. 22: Length 3.76 mm., width 1.98 mm.

Diagnosis. Thick, biconvex, left and right sagitta otoliths. Outer face ornamented with tuberculations in unabraded specimens. Flat dorsal rim, rounded ventral and posterior rims, the latter notched; anterior rim nearly vertical. Inner face flat and smooth. Sulcus completely enclosed, consisting of a spherical ostium and a very small, curved cauda. Colliculi almost filling the sulcus so that it is nearly flush with the inner face.

This is the commonest otolith in the Bognor assemblage and also occurs commonly at most other London Clay exposures in this country.

Otolithus (Ophidiidarum) symmetricus Frost

Plate 2, Fig. 23

1934. *Ot.* (*Ophidiidarum*) *symmetricus* Frost, G. A., *Ann. Mag. nat. Hist.*, (10), **14**, 444, pl. 12, fig. 8.

Dimensions. Length 5.05 mm., width 2.35 mm.

Diagnosis. A left biconvex, sagitta otolith of symmetrical, spherical outline. Outer face smooth; inner face smooth. Sulcus completely enclosed, rather narrow, consisting of an elongated ostium, expanded anteriorly, and a small cauda delineated by a constriction on the crista inferior. No colliculi.

This species was described by Frost from the London Clay, Isle of Sheppey, and occurs rarely at Bognor.

3. CONCLUSIONS

The Bognor otolith assemblage suggests a rather deep-water facies, as shown by the numerous Ophidioid otoliths, adult examples of *Pterothrissus*, *Merluccius* and the pelagic *Monocentris*. Littoral forms occur rarely and only as juveniles, with the exception of the otoliths of *Gadus* and *Ammodytes*. These occur frequently, but it has been shown by Jensen (*Meddelelser fra Kommissionen for Havundersøgelser*, *Fiskeri*, Bind 1, Nr. 7

1905) that otoliths of littoral fishes may be found in large numbers at considerable depths although such fishes are never found living in the areas in which the otoliths are found. However, the presence of numerous beetles in the London Clay at Bognor indicates that land was not far distant and it is more probable that the strata were formed near the edge of a continental shelf. This view is supported by the absence of Scopelid and Macrurid otoliths.

ACKNOWLEDGMENTS

Without the kindly help of many fishery officers and the authorities of fishery research stations and other institutions throughout the world who have supplied me with otoliths from living forms, it would have been impossible to attempt this paper. My thanks are especially due to M. Cadenat of the Laboratory of Marine Biology of I.F.A.N. at Dakar for otoliths of *Pterothrissus belloci* Cadenat, which have enabled me to determine what has previously been an enigma among our Tertiary otoliths. Dr. M. Poll, Director of the Section of Vertebrates, Museum of the Belgian Congo, has very kindly supplied me with many details of the distribution and habitat of *Pterothrissus*.

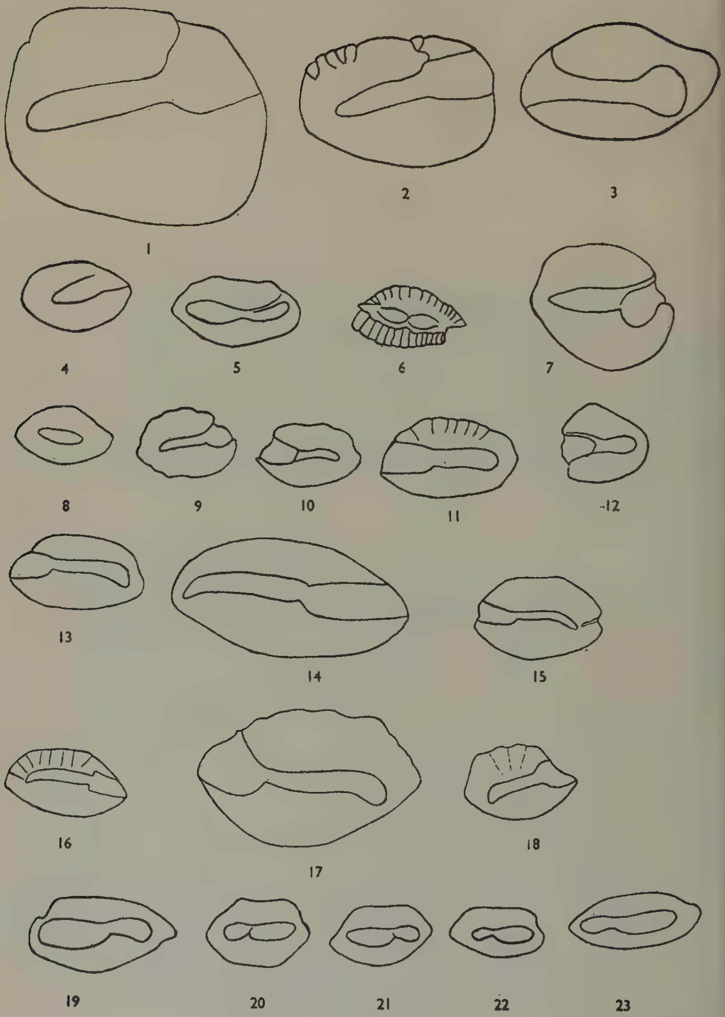
Invaluable assistance has been accorded me by the officers of the Departments of Zoology and Palaeontology, British Museum (Natural History), in the form of access to specimens and books of reference.

Mr. D. Curry has given me much help in the preparation of the paper and without the diligent searching of Messrs. E. M. Venables and H. E. Taylor there would be no material on which to base the subject matter.

I am indebted to Dr. T. K. Owen, Pathologist to the Royal Victoria Hospital, Bournemouth, for his kindness in undertaking the photography of the specimens.

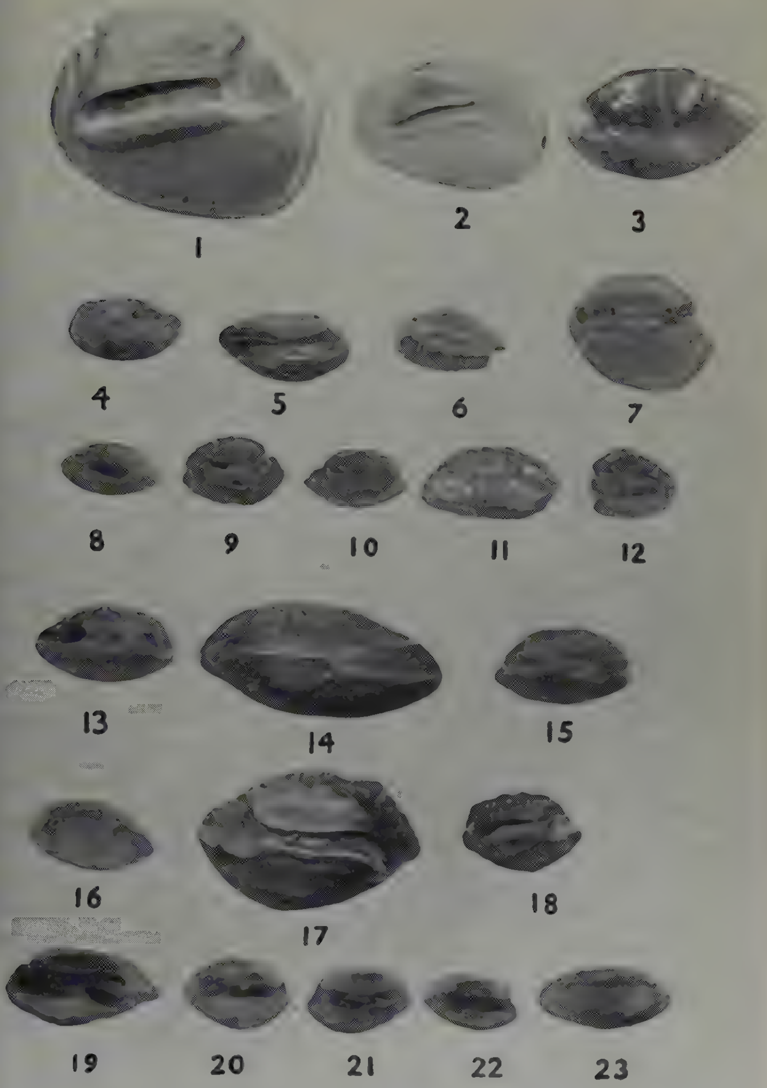
EXPLANATION OF PLATE

Fig. 1. *Pterothrissus umbonatus* (Koken). Inner face. Adult example. Venables collection.
Fig. 2. *Pterothrissus umbonatus* (Koken). Inner face. Juvenile. Lower Barton Beds, Highcliffe. Stinton collection.
Fig. 3. *Conger acutus* n.sp. Inner face. Taylor collection.
Fig. 4. *Uroconger minimus* (Frost). Inner face. Taylor collection.
Fig. 5. *Gadus subnotus* Frost. Inner face. Venables collection.
Fig. 6. *Raniceps planus* Koken. Inner face. Taylor collection.
Fig. 7. *Monocentris lemoinei* (Priem). Inner face. Venables collection.
Fig. 8. *Ammodytes pseudoacuminatus* (Šulc). Inner face. Venables collection.
Fig. 9. *Ot.* (*Serranidarum*) *undulatum* n.sp. Inner face. Taylor collection.
Fig. 10. *Ot.* (*Serranidarum*) *minsterensis* Frost. Inner face. Venables collection.
Fig. 11. *Epinephelus ovalis* n.sp. Inner face. Venables collection.
Fig. 12. *Apogon bellovacinus* (Priem). Inner face. Taylor collection.
Fig. 13. *Centropomus superpendens* Frost. Inner face. Venables collection.
Fig. 14. *Psammoperca sheppeyensis* (Frost). Inner face. Venables collection.
Fig. 15. *Caesio bognoriensis* n.sp. Inner face. Venables collection.



Outlines of otoliths shown in Plate (× 3.6)

Fig. 16. *Pomadasys ovalis* n.sp. Inner face. Venables collection.
Fig. 17. *Dentex pentagonalis* n.sp. Inner face. Venables collection.
Fig. 18. *Ditrema sheppeyensis* Frost. Inner face. Venables collection.
Fig. 19. *Ot.* (*Ophidiidarum*) *productus* n.sp. Inner face. Venables collection.
Figs. 20, 21, 22. *Ot.* (*Ophidiidarum*) *sheppeyensis* Frost. Inner face. Venables collection.
Fig. 23. *Ot.* (*Ophidiidarum*) *symmetricus* Frost. Inner face. Taylor collection.



Otoliths described in this paper. For details, see *Explanation of Plate*, p. 29

[*To face p.* 30

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Certain Abandoned Channels of Pleistocene and Holocene Age in the Lea Valley, and their Deposits

by JOHN. F. HAYWARD

Received 28 May 1954; read 6 April 1956

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ABSTRACT: Temporary sections in the Lea Valley between Hertford and Edmonton have yielded evidence of former channels of the River Lea. The sections are described and their molluscan faunas recorded. A relative chronology is deduced, and where possible, an absolute chronology. Two Pleistocene[2] channels[3] are involved; an early post-glacial one which can be correlated with part of S. H. Warren's sequence at Nazeing, one probably of Romano-British Iron Age, and one later. The paper also describes recent deposits of the river. Except at one horizon, correlation with channel deposits in the Thames Valley is regarded as almost impossible.

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[1] The official spelling of this name is 'Lee' but the more generally accepted spelling 'Lea' is used elsewhere in this paper.

[2] Since this paper was written the author has accepted, though with reservations, the general usefulness of Prof. Flint's concept of the 'Holocene' as Post-Glacial Pleistocene. It is not considered necessary to re-write the text, however.

[3] The term 'channel' is used in this paper to denote a hollow cut by the River Lea and filled with aquatic and other deposits. Two or more 'channels' may be contemporaneous, yet geographically distinct, or one may be superimposed on another as a 'second filling'.

1. INTRODUCTION

ARLY MAPS of Essex (e.g. Chapman and André, 1777) show that the River ea had more than one channel at various places between Waltham Abbey nd Stratford, as exemplified by four or five such channels near Waltham bbey. Some of them still exist, while others have become filled up, and yet thers have been added in the last century or so for drainage or for naviga- on. Those parts of the original river which have been discarded for avigational purposes may eventually cease to exist—a fate which has lready overtaken those swallowed up by the large reservoirs. The 'alluvial' eposits in the flood-plain of the river show evidence of former channels ith abundance of molluscan, vertebrate and plant remains.

The main intention of this investigation is to provide a relative chrono- ogy of various deposits of Pleistocene and Holocene date, based chiefly on study of the commoner molluscs. Certain aspects of the work which are eyond the scope of this programme include the identification of the naller Pisidia and of the fruits and seeds from the peats and other eposits.

2. SUMMARY OF PREVIOUS RESEARCH

During the latter part of the nineteenth century practically the whole idth of the flood-plain in the Tottenham area became occupied by new eservoirs, and the excavations for these yielded evidence of ancient annels now filled by sediments (Wilson, 1897; Woodward, H., 1884; olmes, T. V., 1901, 1902; Anon., 1901). In general the deposits were mited below by the Flood-Plain Gravels, into which the channels gener- ly cut, and above by the yellow-brown marsh clay which is ubiquitous the Lea Valley. Usually the infillings of the channels were described as oams' and similar deposits, often associated, laterally or otherwise, with eats.

Shells collected from these deposits were not often recorded bed by bed. ome authors quoted faunal lists within a small exposure which they did ot usually subdivide. Kennard's lists (e.g. Kennard & Woodward, 1897) ere biological rather than stratigraphical.

That some of the sections represented channels which were waterways historical times was demonstrated by associated finds of a 'Viking' ship nd of a dugout canoe of 'Romano-British' origin. A similar find is escribed in Section 5 of this paper.

Mr. S. H. Warren, investigating Pleistocene channels near Nazeing 934, 1952), discovered one deposit of Holocene age a short distance from arthagena Lock. This he mentioned briefly (1940). Later, the present ithor discovered the same deposits independently and Mr. Warren enerously handed over his material and waived his interests in the site. It was these deposits (Section 6, below) which caused the present enquiry to be started.

3. MIDDLE LEE SEWAGE DISPOSAL WORKS, RYE MEADS, HERTS

These excavations were well advanced when the author made his first visit to them. No recognisable river-channel deposits were seen, though a member of the Resident Engineer's staff reported that one with a peat infilling had been exposed at an earlier date. Features which the author was able to examine included depressions filled with a series of deposits of which the following was typical:

	ft.	in.
4. Soil	1	6
3. Yellow-brown clay	2	0
2. Grey boulder clay or solifluxion gravel often penetrated by rootlets	2	0
1. Flood-Plain Gravel	base not seen	

In most places where this sequence was seen it was quite localised and elsewhere a simpler one was observed:

	ft.	in.
3. Soil	1	6
2. Sandy gravel with some admixed clay	2	6
1. Flood-Plain Gravel		

Here and there the Flood-Plain Gravel was leached white and resembled a Holocene gravel rather than a Pleistocene one. Elsewhere, particularly in horizontal bands of which two were seen, gravel was cemented by limonite into a conglomerate or 'pan'. Clearly there had been considerable circulation of water, with numerous changes in the iron content of the gravel. Doubtless this was bound up with the fact that here the gravel lay directly on the Chalk without the intervening Eocene deposits which are found further south.[1] The Chalk, which the author did not see, must have provided a ready route by which water could pass away except under certain conditions when deposition of limonite could take place.

Some problems were answered by an examination of trial borehole records held by the consulting engineers. These provided no evidence of a channel infilled with peat, as mentioned above. Rather they suggested that the peat (which was associated laterally with sandy clays and similar deposits) filled hollows in the irregular surface of the Flood-Plain Gravel. On the other hand the borings demonstrated what appeared to be a channel cut in the surface of the Chalk and, since this channel was filled with Flood-Plain Gravel, clearly it was of Pleistocene age. In Fig. 1 is shown the area

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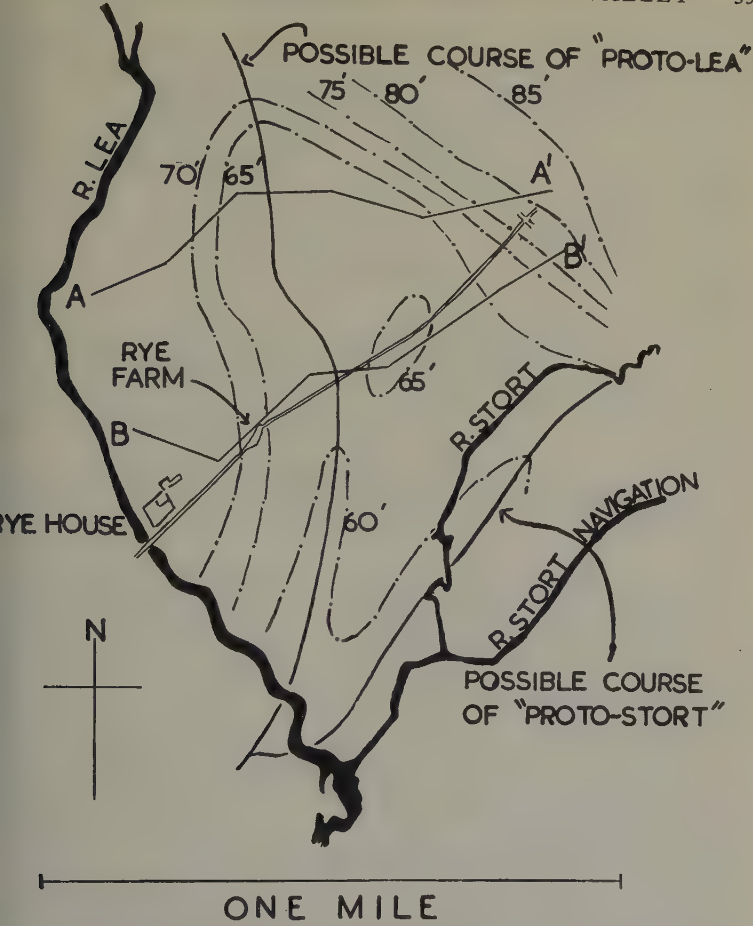
[1] Thin deposits which may be Reading Beds were found in borings in the south-west part of the site.



. 1. The area of Rye Meads Sewage Works showing the estimated contours of the alk surface. Based (by permission) on a map prepared for the Harlow Development rporation.

d the probable contours of the Chalk surface concerned. It is based on a p produced by the engineering geologist who was consulted by the ponsible Corporation. The lines AA′ and BB′ join several of the bore-les and the sections along these lines, conjectural between boreholes, are own in Fig. 2. The map suggests one north–south channel and possibly a ond channel, extending from the north-east, which may join the first in manner indicated. A bold, but not too improbable, suggestion would that these channels represent a Pleistocene Proto-Lea and Proto-Stort pectively.

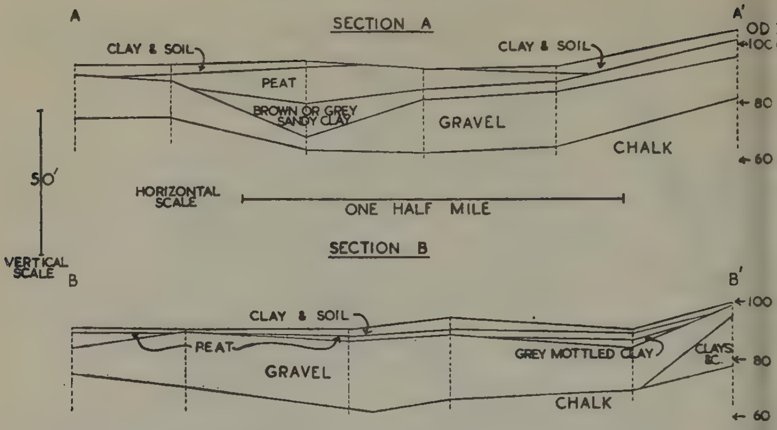


Fig. 2. Rye Meads Sewage Works. Sections along the lines AA′ and BB′ on the map in Fig. 1. Boreholes shown by dotted lines. The disposition of beds between boreholes is conjectural.

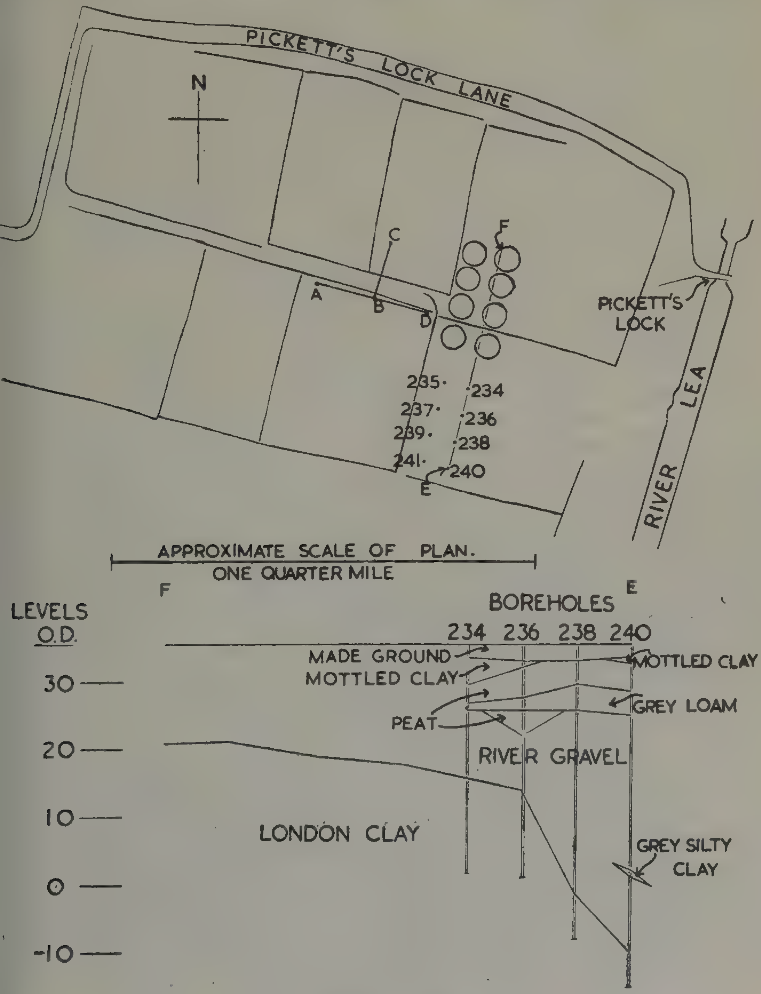
In parts of the site, depressions in the irregular surface of the gravel contain boulder clay or solifluxion gravel. Therefore these depressions are of Pleistocene age and possibly they are interglacial run-off channels. North of the road, i.e. approximately north of the line of Section BB′. Fig. 2, the depressions are filled by silty or sandy clay and associated peat which peat thickens to the north. South of the road are the deposits mentioned at the beginning of this section, the peat being non-existent except for a small tongue which crosses the road from the north. The peat and associated clays are followed by yellow-brown marsh clay and this, in turn, by soil.

From these facts it follows that whereas the ‘channel’ reported by the site engineers cannot be accepted as such, there is undoubted evidence of either a late Pleistocene channel, or of two such channels which are possibly precursors of the present Lea and Stort.

4. EAST MIDDLESEX MAIN DRAINAGE SCHEME—DEEPHAMS SEWAGE WORKS

(a) **The Pleistocene Channel.** Results obtained from the sinking of some three dozen boreholes in connection with this scheme have been described already (Hayward, 1955). An account of information derived from eight other boreholes within the area of the sewage works was postponed. The area concerned is shown in Fig. 3, together with the positions of the eight boreholes and the site of the excavations. In the same figure is given the section proved by the boreholes and the estimated extension of this section seen in certain excavations. It demonstrates the presence of a deep annel cut in London Clay and filled with deposits of later date. The annel is of Pleistocene age and from the fact that it descends to below rdnance Datum, and is infilled by gravel of Flood-Plain date, it appears be of 'buried channel' age.

About ten feet above the lowest point reached in the borings was a lens



g. 3. *Above:* Plan of the area of Deephams Sewage Works showing the site of bore-les and the lines of sections given in Fig. 4. *Below:* Section along the line EF in the ove plan.

of pebbly silt which may possibly be a representative of the Arctic Bed c the Ponders End Stage. Mr. S. H. Warren agrees that the sample which h has examined from Borehole 241 could be Arctic Bed, though it is atypica both as regards its lithology and position, and no certainty about its ag could be entertained in the absence of fossil evidence. In some ways it wa similar to an occurrence of undoubted Arctic Bed which was discovere later, a short distance to the north, outside the region of the Pleistocen channel.

These borings also show the extreme edge of a deposit of Holocene dat apparently associated with the channel to be described in the next section The brown mottled clay in Borehole 237 passes laterally into shell marl i Borehole 235. This marl was found to contain molluscs of Holocene type most of which were represented by single specimens in the sampl examined:

Theodoxus fluviatilis (Linné)	several
Valvata cristata Müller	
Valvata piscinalis (Müller)	
Bithynia tentaculata (Linné)	common
Lymnaea palustris (Müller)	
Lymnaea sp. juv. cf. *L.* [*Radix*] *peregra* (Müller)	
Planorbis [*Bathyomphalus*] *contortus* (Linné)	
Hygromia [*Trichia*] *hispida* (Linné)	

From its level, this bed is later in date than Bed 3 of the Holocene channe of the next section. It will be referred to as 'Bed 4'.

(b) **The Holocene Channel.** A little to the north of the trial borings jus described was a large excavation intended for several sewage tanks. Thi revealed a complex series of deposits which were somewhat difficult t study as a whole on account of continuous changes in the site as excavations proceeded. Some idea of part of the sequence can be obtained fro Fig. 4. The map in Fig. 3 shows the approximate lines along which th sections were drawn. The following deposits were examined on the site:

	ft. i
6. Brown Clay	generally 1 ft. to 3 f
5. Impersistent peat beds (one or two) with or without gravel parting	variabl
4. Shell Marls, Bed 2 and Bed 3	2
3. Marly silt without shells, Bed 1	2
2. Gravel of Flood Plain, with rafts of Arctic Bed just above the base	variabl
1. London Clay	seen to 2

The surface of the London Clay undulated slightly and was seen alon the north face of the excavation at about the level of the base of the pi (approx. 23 ft. O.D.). Everywhere the clay was blue-grey in colour an

(*Photo J. F. H.*)

Deephams Sewage Works. Part of section near to the line B–C in Fig. 3 and Fig. 4. eds visible are:

4. Marsh Clay.
3. Peat.
2. Marls of the Holocene channel (subdivisions not distinguishable).
1. Flood-Plain Gravel.

Beds 1 and 2 are partly in shadow. The marls are approximately 4 ft. in thickness.

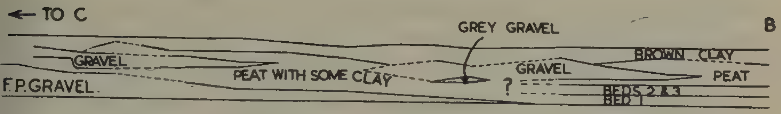
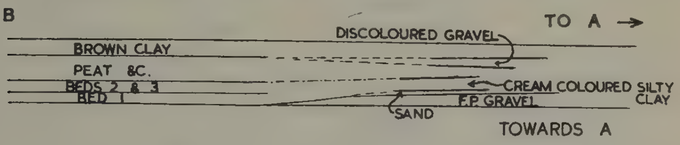


Fig. 4. Deephams Sewage Works. *Above:* Section along the line B–C in Fig. 3. Section measured at frequent intervals with intermediate parts inserted by eye. Dotted lines conjectural. *Below:* Approximate section (much idealised) along part of the line A–B in Fig. 3. Measured at widely spaced intervals. Dotted lines conjectural.



nowhere was it found to be weathered brown at the surface. This agrees with observations already published (Hayward, 1955).

The Arctic Bed, identified by Mr. Warren, consisted of small rafts, a few feet long and not more than about 1 ft. thick, occurring at a foot or so above the base of the gravel. It consisted of a buff sandy clay with pebbles, passing here and there into a similar clay which was black in colour. Washing of some samples was carried out with disappointing results but more material has since been examined and will be dealt with elsewhere.

The Flood-Plain Gravel itself had no special features warranting description. It was cut into by a shallow channel some 150 ft. wide and probably not more than 8 ft. deep. The bottom of this channel was filled with a series of marls as follows:

Bed 3: Shell marl with abundant Charophytes and some plant debris
Bed 2: Shell marl with abundant Charophytes and much plant debris
Bed 1: Marly silt with plant debris. No shells or identifiable plant matter observed in the sample examined

Bed 1 appears to indicate infilling by simple sedimentation and showed no special points of interest. After washing, the residue consisted of fine ounded quartz grains with a smaller percentage of irregular flint grains nd a varying amount of largely unidentifiable plant debris. A few larger ebbles were found. There was, however, a percentage of calcareous matter and one or two small stones were encrusted with calcium carbonate. Hence, although no charophyte fruits were discovered, the activity of lime-ecreting organisms appears to be evident.

Bed 2 and Bed 3 were about 2 ft. in thickness in certain measured ections, so that each one averaged about half of that thickness. The larger mount of plant matter in Bed 2 was clearly noticeable in the section and the junction between the two beds was clean cut. Washing of samples revealed the following assemblages:

	Bed 2	**Bed 3**
Valvata cristata Müller	rare	rare
Valvata [*Cincinna*] *piscinalis* (Müller)	common	rare
Bithynia tentaculata (Linné)	rare	abundant
Lymnaea [*Galba*] *truncatula* (Müller)	none found	rare
Lymnaea [*Stagnicola*] *palustris* (Müller)	rare	rare
Lymnaea stagnalis (Linné)	fairly common (of all ages)	rare (no adults found)
Lymnaea [*Radix*] *peregra* (Müller)	abundant (adults rare)	common (of all ages)
Physa fontinalis (Linné)	common	fairly rare
Planorbis planorbis (Linné)	none found	rare
Planorbis sp. cf. *P.* [*Anisus*] *vortex* (Linné)	rather rare	not found
Planorbis [*Anisus*] *leucostoma* Millet	rare	rare (juveniles only)
Planorbis [*Gyraulus*] *laevis* Alder	abundant	fairly common
Planorbis [*Gyraulus*] *crista* (Linné)	common	fairly common
Planorbis [*Bathyomphalus*] *contortus* (Linné)	none found	rare
Segmentina [*Hippeutis*] *complanata* (Linné)	fairly common	rare
Succinea sp.	none found	rare
Pupilla muscorum (Linné)	rare	rare
Vallonia pulchella (Müller)	none found	rare
Vallonia costata (Müller)	none found	rare
Sphaerium corneum (Linné)	rare	very rare
Pisidium spp.	fairly common	common
Caddis cases	none found	a few
Herpetocypris reptans (Baird)	common	common
Candona candida (Müller)	rare	not found
cf. *Cypridopsis vidua* (Müller)	common	not found
Potamogeton sp. or spp.	abundant	common
Hippuris vulgaris Linné	a few	a few
cf. *Scirpus lacustris* Linné	none found	a few
Ranunculus sp. cf. *R. acris* Linné	rare	rare
Various seeds *indet.*	a few	a few
Charophyte fruits	abundant	abundant

These lists are remarkable from several points of view:

(i) The shell fauna is almost entirely aquatic, without the liberal percentage of adventives which is often found in similar deposits.

(ii) The different frequencies of various shells in the two beds give a clue to contemporary ecological changes.

(iii) The absence of certain species suggests that these beds are earlier than most Lea Valley Holocene deposits.

Certain aspects of the fauna deserve special mention:

Herpetocypris reptans. Dr. J. P. Harding, who identified the ostracods, remarks that it is very common over Europe and North America. Usually it is found in ponds and ditches with muddy bottoms, sometimes burrowing nore or less deeply into the loose mud. Commonly it keeps close to the ottom and is not a swimmer.

Candona candida. This has a variety of freshwater habitats and is com- non in small ponds, or on the margin of lakes. It has a wide distribution n Europe.

Cypridopsis vidua. The specimens found in Bed 2 are referred to this pecies by Dr. Harding, though they are rather larger than usual. He could, iowever, find no other likely species. It is very common, usually in fairly ermanent ponds rich in plants. This agrees with its occurrence in Bed 2 vhich has abundant seeds and other plant debris.

Thus the ostracods indicate that even by the time Bed 2 was accumulat- ng, the channel had become practically, if not entirely, stagnant. The first wo species are recorded from the Arctic Bed also.

The molluscan assemblage bears a very strong resemblance to that of the rctic Bed of which assemblage it is undoubtedly a survivor. The presence f *Planorbis laevis* and *P. crista* in some quantity is typical, and these pecies are never so abundant in later deposits as they are in the Deephams eds. The deposit is dated by its mollusca as early post-glacial and shows a lose relationship to the deposits at Nazeing which were described by Varren in 1952. Samples of certain of Warren's 'M' beds are lithologically imilar and the author correlates the Deephams horizons with them.

The ecology of the fauna indicates a change between Bed 2 and Bed 3. t is possible that one or more of three factors may be involved:

(i) The progressive amelioration of climate with consequent decrease in oreal types.

(ii) The conversion of the channel from a flowing river to a stagnant itch, and

(iii) A change in the hardness of the water.

Possibility (ii) has been discussed above. Probably Bed 1 marks the ilting up by mechanical and other means of a flowing waterway and Bed 2 nd Bed 3 were deposited, largely by Charophytes and similar agencies, in he closed pond or ditch so formed. Also it is quite probable that the hard- ess of the water played an important part. Of the molluscan species which ecome less abundant from Bed 2 to Bed 3, the majority are lovers of soft vater while the reverse is the case with those which increase from Bed 2 to ed 3. This suggests an increase in the hardness of the water with time and nay be tied up with Charophyte activity.

The cases of Caddis larvae did not give much information. It is not ossible to make generic identifications from the empty cases. The half- ozen specimens found in Bed 2 are, however, rather light and delicate, sing a considerable proportion of plant material, and this does not suggest nat their habitat was swiftly-running water.

The plants, like the molluscs, are Pleistocene survivors. In particula the Potamogetons, of which several species are found in the Arctic Bed are abundant. Some of the *Potamogeton* seeds closely resemble those o *P. densus* Linné which inhabits shallow streams. The other identified seeds indicate a variety of habitats but their presence could be due to wind dispersal.

Thus the deposits filling the Deephams channel are of early post-glacia age and contain a large element of the Arctic Bed fossils of which they are survivors. They represent the deposits of a shallow channel which silted up (Bed 1) very quickly and then became a closed ditch, or a very slowly running stream. Tentatively, Bed 3 is correlated with Warren's 'Mx organic mud'.

For some years the higher bed, here designated as 'Bed 4', was known only by the small borehole sample mentioned above and by a handful o material from a dump. Early in 1956, however, a fresh excavation proved its existence *in situ*, though only in an isolated pocket. The bed lay between a thickness of peat and the overlying marsh clay. The following is a preliminary list of the molluscs obtained from a sample:

Theodoxus fluviatilis (Linné)	a few
Valvata cristata Müller	common
Valvata [*Cincinna*] *piscinalis* (Müller)	abundant
Bithynia tentaculata (Linné)	common
Carychium sp.	rare
Lymnaea [*Galba*] *truncatula* (Müller)	rare
Lymnaea stagnalis (Linné)	rare
Lymnaea [*Radix*] *peregra* (Müller)	a few
Planorbis [*Gyraulus*] *albus* Müller	a few
Planorbis [*Gyraulus*] *crista* (Linné)	common
Planorbis [*Bathyomphalus*] *contortus* (Linné)	abundant
Segmentina [*Hippeutis*] *complanata* (Linné)	rare
Acroloxus lacustris (Linné)	rare
Ancylus fluviatilis Müller	rare
Succinea sp.	rare
Cochlicopa sp.	rare
Vertigo sp. or spp.	rare
Clausilia sp.	rare
Helix [*Cepaea*] *nemoralis* Linné	rare
Discus rotundatus (Müller)	fairly common
Vitraea crystallina (Müller)	rare
Retinella [*Aegopinella*] *nitidula* (Draparnaud)	rare
Pisidium spp.	abundant

5. THE TWICKENHAM GRAVEL COMPANY'S PIT, RAMMEY MARSH, WALTHAM CROSS, HERTS

Information concerning this pit was first received from Dr. L. R. Cox. The presence of a substantial channel deposit was causing serious interference with the winning of gravel and the company had sent samples to the British Museum (Natural History). Some mollusca were in the hands of Dr. Cox, and algal material had attracted the attention of the late Mr. W. N. Croft.

The whole of the excavation was under water. Gravel was removed from below the water surface by a grab on a floating pontoon. Surface soil, marsh clay, peat, and the material filling the channel were thrown back into the water so that shells from these deposits floated to the surface, intermingled with seeds and the like. Many thousands of these shells have been collected by the author and by Mr. A. G. Davis who occasionally accompanied him in the field. A large faunal list was obtained, but it represented the aggregate of all species to be found in a variety of deposits.

Information concerning the sequence of beds was obtained from three sources:

(i) The observations of the grab operator whose records of depths were accurate.

(ii) Material from various depths which the grab operator placed on the bank at the author's request.

(iii) The results of auger borings, made by the author across the line of the channel.

The evidence from the third of these sources, modified by the first two and slightly idealised, is included in Fig. 5. The sequence involved is as follows:

9. Topsoil
8. Brown marsh clay
7. Peat or peaty clay
3–6 Infilling of channel – – – – – –
    6. Brown and cream calcareous tufa with balls of 'race'
    5. Light grey peaty clay
    4. Shelly clay
    3. Blue-grey calcareous tufa with balls of 'race' which decrease in size upwards
2. Gravel of Flood Plain
1. London Clay—proved in borings only

These deposits must be regarded as facies indicators rather than as stratigraphical units. Thus, parts of Beds 3 to 6 were contemporary with parts of Bed 7 and Bed 8, and in places these last were contemporary with each other.[1]

Buried in the peat on the west side of this former channel were the remains of a dugout canoe, described as 'Romano-British'. The significance of this discovery is discussed below.

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[1] The correctness of this assumption has now been proved by augering carried out in May 1956.

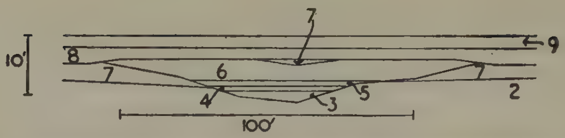
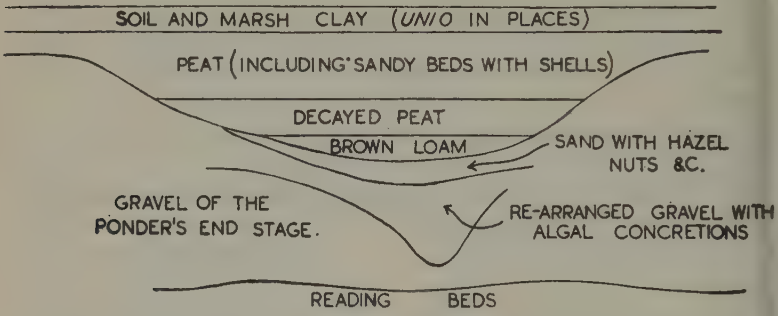


Fig. 5. *Above:* Section across the Rammey Marsh channel near the south end of Lea Road. Based on auger borings made by the author modified by the examination of material obtained from the channel and slightly idealised. *Below:* Diagrammatic section across S. H. Warren's 1947 channel, based on a manuscript drawing by Mr. Warren.


SOIL AND MARSH CLAY (*UNIO* IN PLACES)
PEAT (INCLUDING SANDY BEDS WITH SHELLS)
DECAYED PEAT
BROWN LOAM
SAND WITH HAZEL NUTS &C.
GRAVEL OF THE PONDER'S END STAGE.
RE-ARRANGED GRAVEL WITH ALGAL CONCRETIONS
READING BEDS

It has been necessary to relate the fauna obtained from the floating samples to the various beds listed above. This could be done with some exactness by collecting from material deliberately dredged from recorded depths. As a result most of the species have been located stratigraphically. Some others could be placed with reasonable certainty. For example, specimens encrusted with calcium carbonate were presumably from the calcareous beds.

Some of the material from the latter beds had been studied by Mr. W. N. Croft who wrote a brief description. This he read to the author a few months before his death but it has not been found among his papers subsequently. However, the gist of it was that on the evidence afforded by the presence of pyrite, Mr. Croft believed the calcareous matter was due to blue-green algae. The action of such organisms was well evidenced in Bed 3 and Bed 6 of the sequence.

A comparison was made of the molluscs obtained from the various beds filling the channel but the results demonstrated that no useful purpose would be served by treating them separately in this report.

The shells which floated to the surface in the flooded pit remained floating for a time and then sank to the bottom, some species remaining at the surface for longer periods than others. Thus, material collected at different times yielded shells of particular species in different proportions.

Even dredged samples, when washed, gave very different suites of molluscs. Consequently the relative frequency given below is based on a compromise between the floating shells and those obtained from the deposits themselves:

Theodoxus fluviatilis (Linné)	rare
Valvata cristata Müller	common
Valvata [*Cincinna*] *piscinalis* (Müller)	abundant
Bithynia tentaculata (Linné)	abundant
Carychium minimum Müller	very rare
Lymnaea [*Galba*] *truncatula* (Müller)	very rare
Lymnaea [*Stagnicola*] *palustris* (Müller)	fairly common
Lymnaea stagnalis (Linné)	common
Lymnaea [*Radix*] *peregra* (Müller)	abundant
Physa fontinalis (Linné)	very rare
Planorbis carinatus Müller	common
Planorbis planorbis (Linné)	common
Planorbis [*Gyraulus*] *albus* Müller	rare
Planorbis [*Gyraulus*] *crista* (Linné)	common
Planorbis [*Bathyomphalus*] *contortus* (Linné)	very rare
Segmentina nitida (Müller)	rare
Acroloxus lacustris (Linné)	rare
Ancylus fluviatilis (Müller)	rare
Succinea sp.	very rare
Cochlicopa lubrica (Müller)	very rare
Vertigo antivertigo (Draparnaud)	very rare
Pupilla muscorum (Linné)	common
Vallonia pulchella (Müller)	very rare
Vallonia costata (Müller)	very rare
Clausilia bidentata (Ström)	very rare
Helix [*Cepaea*] *nemoralis* Linné	fairly common
Hygromia [*Trichia*] *hispida* (Linné)	very rare
Limax sp.	rare
Slug granules	rare
Sphaerium corneum (Linné)	rare
Pisidium spp.	common
Charophyta	very rare
Plant galls	common
Fruits and seeds, various spp.	common

This list bears a close resemblance to that given for 'Bed 4' at Deephams, with which bed it is proposed to correlate it. But whereas the Deephams bed was an isolated pocket, and contained a higher percentage of land shells, this fauna is from the main channel. This accounts for the differences in the two lists.

The dugout canoe was found at seven feet below the surface of the water, within the peat which bordered the channel. Among the molluscs in a small sample of the material from the underside of this boat were more than two dozen *Planorbis acronicus* and a dozen or so of *Bithynia leachi*.

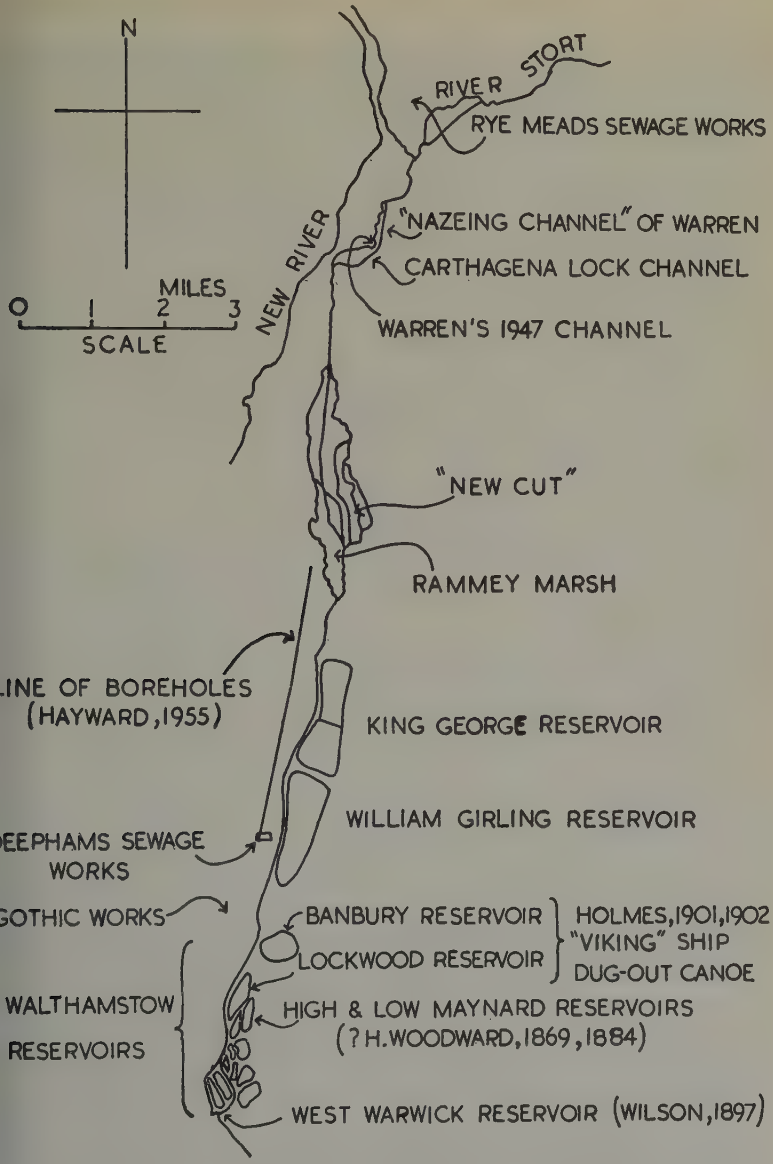
Otherwise the fauna agreed roughly with that quoted in the previous paragraph. It is argued elsewhere (Holmes & Hayward, 1955) that these snails were actually living on the underside of the boat when it was beached. In other words, they are earlier than at least a part of the fauna quoted above since they belong to a time when the channel was occupied by water. However, they had an extremely limited habitat from which they did not apparently spread during the lifetime of this particular channel. It is of course possible that the boat had drifted downstream from a part of the river in which these shells were locally abundant.

The following is a faunal list, obtained from the 'boat' sample:

Theodoxus fluviatilis (Linné)	rare
Valvata cristata Müller	very rare
Valvata [*Cincinna*] *piscinalis* (Müller)	abundant
Bithynia tentaculata (Linné)	abundant
Bithynia leachi (Sheppard)	common
Lymnaea [*Galba*] *truncatula* (Müller)	very rare
Lymnaea [*Radix*] *peregra* (Müller)	rare
Planorbis planorbis (Linné)	rare
Planorbis [*Anisus*] *vortex* (Linné)	rare
Planorbis [*Anisus*] *leucostoma* Millet	rare
Planorbis [*Gyraulus*] *albus* Müller	rare
Planorbis [*Gyraulus*] *acronicus* Férussac	common
Planorbis [*Bathyomphalus*] *contortus* (Linné)	rare
Acroloxus lacustris (Linné)	very rare
Ancylus fluviatilis Müller	very rare
Succinea sp.	very rare
Vallonia costata (Müller)	very rare
Hygromia [*Trichia*] *hispida* (Linné)	very rare
Oxychilus cellarius (Müller)	very rare
Retinella [*Perpolita*] *radiatula* (Alder)	very rare
Pisidium spp.	a few
Charophyta	very rare

Generally the yellow-brown marsh clay was three or four feet in thickness in the area, but over the channel itself its base rose so that the thickness was only 2 ft. or 2 ft. 6 in. Its examination has already proved fruitful (Hayward, 1954) and the washing of a sample yielded a good list of land and marsh snails. These are quoted in Section 8 below and the deposit is further discussed in the paper already referred to (Holmes & Hayward, 1955).

When the lists given above have been studied there remain some seventeen species which have not been found *in situ*. Of these some were found in samples of peaty material which Mr. A. G. Davis found on a spoil heap during one of his visits with the author. This may perhaps represent part of Bed 4 and Bed 5 of the sequence. The list of shells from the sample was not very different from the lists already quoted but it included some species which have not been accounted for elsewhere. Only these last are given in



ig. 6. Map of the area dealt with in this paper, with location of sites mentioned therein nd in earlier literature.

the following list. All were rare, or very rare, except those marked otherwise:

Carychium tridentatum (Risso)	fairly common
Planorbis [*Anisus*] *vortex* (Linné)	
Planorbis [*Anisus*] *leucostoma* Millet	common
Segmentina complanata (Linné)	
Vertigo pusilla Müller	
Vertigo pygmaea (Draparnaud)	
Vertigo moulinsiana (Dupuy)	
Vertigo [*Vertilla*] *angustior* Jeffrys	
Cecilioides acicula (Müller)	
Discus rotundatus (Müller)	
Euconulus fulvus (Müller)	

The lists given above account for the whole of the species collected from the floating material, with the exception of a mere handful. Most of these last were very rare and of no great ecological importance. They were:

Carychium minimum Müller
Punctum pygmaeum (Draparnaud)
Oxychilus helveticus (Blum)
Retinella [*Aegopinella*] *nitidula* (Draparnaud)

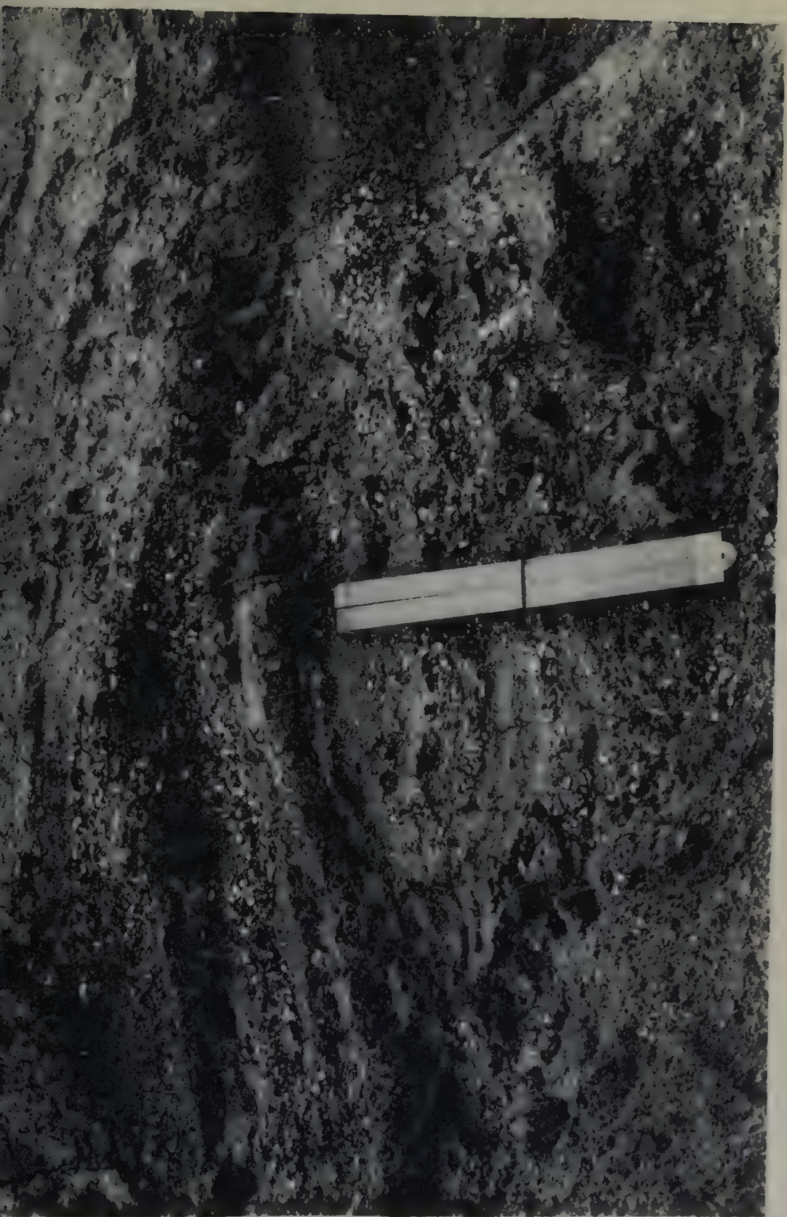
The deposits of this channel, i.e. the infillings and the bordering peat, must be regarded as of late prehistoric or early historic age, on the evidence of the boat. The question has been discussed fully by Mr. J. Holmes (Holmes, 1952; Holmes & Hayward, 1955). Thus, the boat gives a rough dating to this deposit, and the one which was referred to in earlier sections of this paper as 'Bed 4' is so similar faunally that it may be of the same approximate age.

6. THE HOLOCENE CHANNEL NEAR CARTHAGENA LOCK, NAZEING, ESSEX

Because of the presence of a public right of way across Nazeing Mead from near Carthagena Lock towards Peck's Hill, Nazeing, Essex, it became necessary for a narrow strip of ground to be left between two gravel pits, both now flooded. This strip crossed and exposed to view a small channel, rich in shells and other remains, which differed considerably from those already described. This channel, discovered independently by Mr. S. H. Warren and the present author, was visited by the Geologists' Association 6 July 1952. The site has since been fenced off and largely obliterated by further excavations.

Three beds were involved of which the first cut well into the Flood-Plain Gravel. Only this first bed will be considered in this section, the other two being relegated to Sections 7 and 8 respectively:

3. Marsh clay similar in appearance to that found in other parts of the Lea Valley



(*Photo J. F. H.*)

Current-bedded shell-sands with drift peat infilling the Carthagena Lock channel. The overlying grey loam is just visible in the top left-hand corner.

2. Marl with plant debris, etc.
1. Current-bedded shell-sands with marl and drifted peat

There was little doubt that Bed 1 was of torrential or flood origin. This s borne out by its current-bedded nature and by pieces of derived peat vhich were included. The biota consisted of an admixture of freshwater hells and land shells, mammalian bones, insect remains, seeds and plant galls, an assemblage which suggested that the bulk of the material was lerived from the re-sorting of one or more previously existing deposits. These facts imply that at various times the river changed its course in such way as to cut through one or more of its previously abandoned channels nd that the material thus eroded was accumulated under torrential conlitions by a number of floods. It is reasonably certain that one of the older hannels destroyed in this manner was a local equivalent of that at Ramney Marsh, for the shells include some encrusted with lime in a manner ypical of that channel. It is quite certain, however, that at least one other auna, rich in *Bithynia leachi*, is involved as well. Although *B. leachi* is bundant in Bed 1 it is not accompanied by *Planorbis acronicus*, as it was n the Rammey Marsh 'boat' sample. This suggests that, after a lapse of ime, the one species had flourished and spread whereas the other had lready lost its grip. In addition there are certain species, not found in arlier Lea Valley deposits, which are seen for the first time and they may ave been living in the stream, or on its banks. They may be contemporary vith the deposit. Such are *Lymnaea auricularia*, *Planorbarius corneus*, *Anodonta minima* and *Arianta arbustorum*.

The author made careful dimensioned drawings of the various beds. amples were then taken from one lens or another, to ascertain whether here were any faunal differences in the beds. None of any significance was ound though in several cases the larger shells (such as the rare *Anodonta* nd the larger *Lymnaeas* and *Planorbis*) were at the bottom of a lens, thus uggesting a sorting in the process of sedimentation.

The following is a faunal list from Bed 1:

Theodoxus fluviatilis (Linné)	common
Valvata cristata Müller	common
Valvata [*Cincinna*] *piscinalis* (Müller)	abundant
Bithynia tentaculata (Linné)	abundant
Bithynia leachi (Sheppard)	common
Carychium minimum Müller	rare
Carychium tridentatum (Risso)	fairly common
Lymnaea [*Galba*] *truncatula* (Müller)	common
Lymnaea [*Stagnicola*] *palustris* (Müller)	common
Lymnaea stagnalis (Linné)	fairly common
Lymnaea [*Radix*] *auricularia* (Linné)	a few
Lymnaea [*Radix*] *peregra* (Müller)	abundant
Aplecta hypnorum (Linné)	very rare
Physa fontinalis (Linné)	fairly common

Planorbarius corneus (Linné)	fairly common
Planorbis carinatus Müller	common
Planorbis planorbis (Linné)	common
Planorbis [*Anisus*] *vortex* (Linné)	common
Planorbis [*Anisus*] *leucostoma* Millet	fairly common
Planorbis [*Gyraulus*] *albus* Müller	common
Planorbis [*Gyraulus*] *crista* (Linné)	fairly common
Planorbis [*Bathyomphalus*] *contortus* (Linné)	common
Segmentina [*Hippeutis*] *complanata* (Linné)	very rare
Acroloxus lacustris (Linné)	fairly common
Ancylus fluviatilis Müller	common
Succinea sp.	common
Cochlicopa lubrica (Müller)	fairly common
Vertigo antivertigo (Draparnaud)	rare
Vertigo pygmaea (Draparnaud)	rare
Pupilla muscorum (Linné)	fairly common
Vallonia costata (Müller)	rare
Vallonia pulchella (Müller)	fairly common
Arianta arbustorum (Linné)	common
Helix [*Cepaea*] *nemoralis*	rare
Hygromia [*Trichia*] *hispida* (Linné)	common
Hygromia [*Trichia*] *liberta* (Westerlund)	common
Monacha [*Ashfordia*] *granulata* (Alder)	rare
Punctum pygmaeum (Draparnaud)	very rare
Discus rotundatus (Müller)	very rare
Euconulus fulvus (Müller)	rare
Vitrea crystallina (Müller)	very rare
Oxychilus cellarius (Müller)	very rare
Retinella [*Perpolita*] *radiatula* (Alder)	rare
Retinella [*Aegopinella*] *nitidula* (Draparnaud)	very rare
Zonitoides nitidus (Müller)	very rare
Limax sp.	very rare
Slug granules	common
Anodonta minima Millet	very rare
Sphaerium corneum (Linné)	common
Pisidium amnicum (Müller)	common
Pisidium spp.	common

In addition to the above molluscan list there were also Caddis cases and other insect remains, bones of small mammals, seeds and plant galls.

The plant galls from this and other horizons in the Lea Valley are the subject of a separate investigation. Some from Carthagena Lock are tentatively identified as oak galls. Also it is probable that some or all of the Rammey Marsh galls are from the oak. This suggests the abundance of oak trees in the neighbourhood, but it is probable that many of the Carthagena Lock galls were derived from the earlier horizon (Hayward, 1956b).

7. THE GREY LOAMS

A number of shallow sections in the valley reveal that below the topsoil there is a deposit of yellow-brown marsh clay (Section 8 of this paper), elow which there is frequently a grey loamy deposit with shells and often ith the remains of large mammals. Bed 2 of the Carthagena Lock quence is an example of this deposit. Certain other sections have proved similar loam below the marsh clay though none has proceeded to a depth hich made it possible to demonstrate a channel. Two of these deposits are escribed below after which the loams are discussed in general terms.

(a) **The Gothic Works, Angel Road, Edmonton.** Early in 1950, and again vo years later, pits were dug in the Press Shop of Messrs. R. & A. Main td., Edmonton. The excavations were approximately 620 ft. due south of e entrance to the works in Angel Road, Edmonton, N.18. They were out 40 ft. apart and the surface of each was about 34.0 O.D.

The first excavation was not visited, but samples, together with details f the section, were sent by the owners to the British Museum (Natural istory). The faunal list given below includes specimens now in the custody f the Museum. The following is the section quoted:

	ft.
5. Yellow clay	3–4
4. Bluish clay	4–5
3. Shell-bearing layer	Thickness not recorded
2. Peaty clay with wood and bones	
1. Gravel	

he depth of the excavation was 12 ft.

The 1952 excavation was visited independently by Mr. C. P. Castell and e author, and their observations, made while the work was at different ages, are combined to give the following section:

	ft.
4. Surface (concrete)	up to 1
3. Alternations of yellow-brown clay and grey silty clay. The yellow clay predominates in the top half and the grey silty clay in the lower half	9
2. Grey silty loam	3
1. Gravel	seen at about 13

The grey silty clay was rich in organic matter including plant debris, olluscs and bones. The mineral Vivianite was present.

The silty loam in the lowest 3 ft. resembles the similar deposits in other rts of the valley and yielded a small assemblage of shells, the names of hich are given later.

(b) **The 'New Cut', Waltham Abbey, Essex.** During the early 1950's it as decided to cut a drainage channel on the Essex side of the River Lea, ar Waltham Abbey. This channel, now known as the 'New Cut', passes rough the grounds of the Explosives Research and Development tablishment and the author was privileged to pay it a visit by courtesy of e Chief Superintendent. The cut was excavated mainly through gravels t here and there it met deposits not unlike some of those already studied or the courses of existing streams which form part of the Lea network i that area. The material could be examined only in the dumps which line the cut and samples from various sites were selected. The faunas demonstrated that the material represented two rock types which, in thei presumed order of superposition, are:

2. Shelly clay and soil
1. Light grey loam with small specks of Vivianite

In addition to these it was possible to collect shells, weathered out on th surface of the dumps, which could not be referred to either of the abov groups. These shells are discussed in Section 9.

(c) **The Faunal Lists.** The grey loams at the various localities in the Le Valley were, in the samples examined, not rich in shells as a whole either a regards species or as regards individuals, though certain bands were ver fossiliferous. Further, they did not represent the haphazard assemblages t be found in some other deposits. Although there is some admixture of lan and freshwater types the faunas bear out the suggestion that the loam represent the condition of tranquil sedimentation with which variou channel phases were concluded. These loams are being regarded as contemporaneous or penecontemporaneous with each other, though this ma be only an approximation to the truth.

The following list gives the remains found in the grey loams of three sites. The similarities shown by the three lists should be stressed. Differences ar possibly due to the different amounts of material available. For that reason no attempt has been made to indicate the relative frequencies with which the various species occur. A cross indicates that the species was present, a dash that it was not found (though it was not necessarily absent) and a question mark that the specimen was damaged and its specific identity was not certain.

	Carthagena Lock	Gothic Works	New Cut
Theodoxus fluviatilis (Linné)	×	×	—
Valvata cristata Müller	×	×	—
Valvata [*Cincinna*] *piscinalis* (Müller)	×	×	×
Bithynia tentaculata (Linné)	×	×	×
Bithynia leachi (Sheppard)	×	×	×
Carychium minimum Müller	×	—	—
Carychium tridentatum (Risso)	×	—	—
Lymnaea [*Galba*] *truncatula* (Müller)	×	—	—
Lymnaea [*Stagnicola*] *palustris* (Müller)	×	—	—
Lymnaea stagnalis (Linné)	×	×	×
Lymnaea [*Radix*] *auricularia* (Linné)	×	—	—
Lymnaea [*Radix*] *peregra* (Müller)	×	?	×
Physa fontinalis (Linné)	×	—	—
Planorbarius corneus (Linné)	×	—	—
Planorbis carinatus Müller	×	—	—
Planorbis planorbis (Linné)	×	×	×

	Carthagena Lock	Gothic Works	New Cut
Planorbis [*Anisus*] *vortex* (Linné)	×	—	×
Planorbis [*Anisus*] *leucostoma* Millet	×	—	—
Planorbis [*Gyraulus*] *albus* Müller	×	?	×
Planorbis [*Gyraulus*] *crista* (Linné)	×	—	—
Planorbis [*Bathyomphalus*] *contortus* (Linné)	×	—	—
Acroloxus lacustris (Linné)	×	—	—
Ancylus fluviatilis Müller	×	×	—
Succinea sp.	×	×	×
Succinea cf. *elegans* Risso	×	—	—
Cochlicopa lubrica (Müller)	×	—	—
Vertigo antivertigo (Draparnaud)	×	—	—
Vertigo pygmaea (Draparnaud)	×	—	—
Pupilla muscorum (Linné)	×	—	×
Vallonia costata (Müller)	—	×	×
Vallonia pulchella (Müller)	×	—	—
Vallonia excentrica Sterki	—	—	×
Arianta arbustorum (Linné)	×	—	—
Helix [*Cepaea*] *nemoralis* Linné	×	—	—
Hygromia [*Trichia*] *hispida* (Linné)	×	×	×
Hygromia [*Trichia*] *liberta* (Westerlund)	×	—	—
Agriolimax sp.	×	—	—
Slug granules	×	×	—
Sphaerium corneum (Linné)	×	×	—
Pisidium amnicum (Müller)	×	×	×
Pisidium spp.	×	×	×
Beetle elytra	—	×	×
Caddis cases	×	×	—
Equus caballus Linné	—	×	—
Bos sp.	×	×	—
Cervus elaphus Linné	—	×	×
? *Capreolus capreolus* (Linné)	—	×	—

8. THE MARSH CLAYS AND MARSH SOILS

The yellow-brown marsh clays which are everywhere just below the rface are extremely variable in their fossil content. Further, as is the case some other deposits already discussed, the fossils cannot be regarded as fauna' in any sense. Kew (1893) described how river shells are carried to marsh land by a river in flood. Today, shells collected along the strand es of the Lea include not only river and land molluscs recently dead but o demonstrably fossil shells derived from some of the deposits already scussed. In fact the shells of the marsh clays must contain material from three sources and in each case they include specimens from further stream in addition to those of the locality concerned. The shells obtained om the clays at various localities are quoted without discussion therefore.

The most typical molluscs of these marshes are the slugs, and it is sometimes found that when a marsh clay has been broken down and washed the residual sand contains a high proportion of slug granules. Two aspects o the slug fauna of the marsh clays have been discussed already (Hayward 1954, 1954a, 1956).

The absence of certain types is more significant than the presence o others, and this matter will be discussed in succeeding sections. The following assemblage was obtained by washing marsh clays from three localities:

	Rammey Marsh	Carthagena Lock	New Cut
Theodoxus fluviatilis (Linné)	—	—	×
Valvata cristata Müller	—	×	×
Valvata [*Cincinna*] *piscinalis* (Müller)	—	×	×
Bithynia tentaculata (Linné)	×	×	×
Bithynia leachi (Sheppard)	—	×	×
Carychium minimum Müller	—	×	—
Carychium tridentatum (Risso)	—	×	—
Lymnaea [*Galba*] *truncatula* (Müller)	—	×	×
Lymnaea [*Stagnicola*] *palustris* (Müller)	—	×	×
Lymnaea stagnalis (Linné)	—	—	×
Lymnaea [*Radix*] *peregra* (Müller)	—	×	×
Physa fontinalis (Linné)	—	—	×
Planorbis carinatus Müller	—	×	—
Planorbis planorbis (Linné)	×	×	×
Planorbis [*Anisus*] *vortex* (Linné)	—	×	×
Planorbis [*Anisus*] *leucostoma* Millet	—	×	×
Planorbis [*Gyraulus*] *albus* Müller	—	×	×
Planorbis [*Gyraulus*] *acronicus* Férussac	—	×	—
Planorbis [*Gyraulus*] *crista* (Linné)	—	×	×
Planorbis [*Bathyomphalus*] *contortus* (Linné)	—	×	×
Acroloxus lacustris (Linné)	—	×	×
Ancylus fluviatilis Müller	—	×	×
Succinea sp.	×	×	×
Cochlicopa lubrica (Müller)	×	×	×
Vertigo antivertigo (Draparnaud)	—	×	—
Vertigo pygmaea (Draparnaud)	—	×	×
Pupilla muscorum (Linné)	—	×	—
Vallonia costata (Müller)	×	—	—
Vallonia pulchella (Müller)	×	×	×
Arianta arbustorum (Linné)	—	×	—
Helix [*Cepaea*] *nemoralis* Linné	×	×	—
Hygromia [*Trichia*] *hispida* (Linné)	×	×	×
Hygromia [*Trichia*] *liberta* (Westerlund)	×	×	—
Euconulus fulvus (Müller)	—	×	—
Vitrea crystallina (Müller)	—	×	—
Oxychilus cellarius (Müller)	—	×	—
Retinella [*Perpolita*] *radiatula* (Alder)	×	×	—
Retinella [*Aegopinella*] *nitidula* (Draparnaud)	—	×	—
Zonitoides nitidus (Müller)	—	×	×

	Rammey Marsh	Carthagena Lock	New Cut
Limax sp.	—	×	—
Agriolimax cf. *reticulatus* (Müller)	×	—	—
Agriolimax cf. *caruanae* Pollonera	×	—	—
Agriolimax sp.	—	×	—
Slug granules	×	×	×
Sphaerium corneum (Linné)	—	—	×
Pisidium amnicum (Müller)	—	×	×
Pisidium spp.	—	×	×

The sediment from the New Cut shows clearly some differences from the others. It is less of a clay than a soil and may be later than the more typical marsh clays. The comparative abundance of *Bithynia leachi* is striking, and may be due to the erosion of one of the earlier deposits.

9. CONTEMPORARY CHANNELS

It was mentioned in the description of the New Cut that certain shells which were picked up from the tip heap could not be referred to either of he deposits present in the area. These included *Viviparus viviparus* (Linné), arge specimens of *Lymnaea auricularia* (Linné) and two mussels, *Anodonta anatina* (Linné) and *Unio pictorum* (Linné).

Although *L. auricularia* was foreshadowed in the Carthagena Lock deposits, and the mussels by *Anodonta minima*, undoubtedly an adventive, n the same horizon, the former is not found in the same abundance in any Lea Valley deposit yet examined by the author, and neither species of mussel nor the freshwater winkle has yet been found fossil by him in the valley. The specimens collected included some that were obviously alive at a recent date and others which had lain in a deposit which was presumably an unconsolidated mud at the bottom of a stream. From their position on he dump it was clear that the shells were dredged from the bottom of one of the small streams which the New Cut interrupted and that they represent he fauna of a contemporary channel. It is necessary, therefore, to ascertain he date from which such molluscs existed in the Lea system. Although ertain faunal elements are not to be found in the deposits which have been xamined in this investigation, they do occur in some abundance in the Thames Valley which, it would be assumed, formed part of the same faunal province.

Some evidence bearing on the problem comes from excavations carried out nearly a century ago. H. Woodward (1869, 1884) listed the molluscs rom a Shell Marl obtained from the sites of two reservoirs (possibly the High and Low Maynard Reservoirs, which were completed in 1870). The ist includes most of the shells which have become familiar in the preceding ections with one or two additions. Some of the latter were deleted by B. B. Woodward (1891) after an examination of the material in the British

Museum (Natural History) but, even so, there were one or two new forms, quoted above. The presence of *Lymnaea auricularia* and *Planorbarius corneus* together with *Arianta arbustorum* would indicate a date not earlier than Bed 1 at Carthagena Lock. The presence of other members just referred to would suggest a date somewhat later than this.

10. ATTEMPTED CORRELATION OF THE SITES

In order to determine a relative chronology of the events here described it is not necessary to adopt any unusual methods. The Law of Superposition and the Law of Contained Fragments apply, but two assumptions are made, neither of which is unreasonable, though it may be necessary to modify them in the light of later evidence. The first is that the very characteristic material filling the Rammey Marsh channel relates to only one period of history and that no other deposits, identical in their type of sedimentation but differing faunally from the Rammey Marsh deposits, exist. Accepting this assumption it will follow that any deposits, such as Bed 1 of Carthagena Lock, which contain shells encrusted in the manner peculiar to Rammey Marsh are later than that deposit. The second assumption is that the Grey Loams found in different parts of the valley are of one age.

A chronology (based only on the sections referred to in this paper) is now offered, and where possible an attempt will be made to make this an exact chronology.

Late Pleistocene

1. Buried Channel phase. Buried Channels of Deephams and Rye Meads.
2. Aggradation. Infilling of Buried Channel. Flood-Plain Gravel. Arctic Bed of Ponders End Stage. Further Flood-Plain Gravels.
3. ? Formation of possible meltwater run-off channels in Rye Meads area.

Early Post-Glacial

4. Cutting of Holocene channel of Deephams.
5. Deephams Bed 1. Sedimentation largely by inorganic means.
6. Deephams Beds 2 and 3. Sedimentation assisted by Charophytes.

Thereafter certain typical Pleistocene forms cease to be important while still remaining as members of the fauna (*Planorbis crista*, *Planorbis laevis*, *Physa fontinalis*).

7. Incoming of typically Holocene shells (*Theodoxus fluviatilis*, *Planorbis albus*, *Acroloxus lacustris*, *Ancylus fluviatilis*). Some of these are recorded from earlier stages but not, apparently, in such numbers.

? Romano-British Iron Age

8. Cutting of Rammey Marsh channel.

9. Rammey Marsh 'boat' sample. Introduction of *Planorbis acronicus* and *Bithynia leachi* though in a limited habitat.

10. Infilling of Rammey Marsh channel, assisted largely by blue-green algae. Fauna of 'Bed 4'.

? Post-Roman

11. Bed of unknown age (from which much of the material of Bed 1 of Carthagena Lock was derived). *Bithynia leachi* still common but *Planorbis acronicus* had disappeared.

12. Erosion of new channels and re-sorting of material from existing channels. Collection of shells, etc., in Bed 1 of Carthagena Lock. Introduction of new types (*Planorbarius corneus*, *Lymnaea auricularia*, *Aplecta hypnorum*, *Arianta arbustorum*, etc.). First appearance of freshwater mussels. (Rare—? accidental.)

Recent

13. Formation of Grey Loams over parts of the valley.

14. ? Channel of Woodward in Tottenham region. Introduction of Unios, etc.

15. Yellow-brown Marsh Clays formed over the whole area. Faunas extremely local.

16. Existing channels formed, with existing faunas.

11. ATTEMPTED CORRELATION WITH DEPOSITS IN THE THAMES VALLEY

It is possible that some of the gaps in the above scheme may be filled in by a comparison with similar deposits in the Thames Valley. Little helpful evidence is obtained from papers such as those of H. Woodward (1884) and Kennard & B. B. Woodward (1906), which did not describe the faunas stratigraphically. At Penton Hook one of the older sections is of some value in that it is still visible and still being studied. It was first described by Cooper in 1922. Another important exposure is at Otterway's Pit, Chertsey, where not only the faunal elements are important but archaeological correlations have been possible (Howard, 1952). Recently both sites have been visited by the Geologists' Association and are still being investigated by Mr. A. G. Davis and his collaborators. When this work is completed it may be possible to make better comparisons.

Miss Howard refers to several channel deposits at Otterway's Pit. Some of these may be contemporary with each other but there is also a second filling to one of the earlier channels. The significant elements in the faunas are *Planorbis acronicus*, found in some abundance, and *Bithynia leachi*. Both are common in the deposits of Channels A and B, but are absent from the second filling of Channel A and from Channel C, while it appears also in the Flood Loam which may be presumed to be comparable to similar deposits in the Lea Valley. *Anodonta anatina* is found only in one bed of the second filling.

Archaeological evidence quoted in the paper suggests that part of the main channel A is of Iron Age date.

The author understands from Mr. A. G. Davis that the Penton Hook channel was later than the earlier deposits at Otterway's Pit and apparently cut across them. This accounts for the presence of *P. acronicus* which was derived. In addition there were shells of contemporary molluscs such as the mussels and *Viviparus*. The author understands the date is medieval.

There is reasonable certainty that the Rammey Marsh 'boat' sample can be correlated with some part of the earlier deposits at Otterway's Pit. Not only are *P. acronicus* and *B. leachi* helpful guides but, on independent evidence, the two sites are dated as probably Iron Age.

It would be tempting to regard the Penton Hook channel as contemporaneous with certain of the Lea Valley deposits on the grounds that they contain the freshwater mussels as well as the viviparous freshwater winkle. The author has come to the conclusion that such a comparison would be misleading. Such as it is, the evidence from the Lea Valley suggests that, with the exception of *Anodonta minima*, which may have been an accidental introduction at Carthagena Lock, the Unios were very late-comers in the valley, and *V. viviparus*, familiar in the river today, is absent from all except the very latest deposits. Yet they were common in the Penton Hook channel of the Thames. A reasonable suggestion might be that, in the absence of an external method of dispersal, these molluscs would spread from the Thames at an extremely slow rate. The fact that such dispersal was slow was pointed out by Kew (1893). Any migration in the Lea would be against the flow of the water and in the lower Thames might be impeded by tidal, brackish conditions. It is suggested that these molluscs have crept up the Lea only gradually until recent centuries when the linking of the river with the canal system must have played an important part in the dispersal of these shells. Woodward's section in Tottenham could be contemporaneous with others higher up the river in which the new introductions are not found.

It follows that there is little to be gained by an attempt at correlating deposits in the two rivers on a faunal basis and comparisons are best made from archaeological evidence when this is available.

12. APPENDIX: S. H. WARREN'S 1947 SECTION

After the main part of this paper had been written the author discussed its contents with Mr. S. H. Warren. It transpired that in 1947 and 1948 Mr. Warren had seen a peat-filled channel at Broxbourne not far from the

Carthagena Lock site, though on the other side of the river. He had written an account and had drawn a diagrammatic section across the channel but neither the account nor the section had been published. Shells which he had collected were in the British Museum (Natural History). As Mr. Warren was anxious for the details to be placed on record he readily offered it to the author for that purpose. The section is shown in Fig. 5 and the following is Mr. Warren's account of his observations:

'The site is an extension of the former Rikof's, now Inns', pit (1934. *J. R. Anthrop. Inst.*, **64**, 101). It is 400–600 yds. to the north-east of the old pit, 800 yds. east of the Broxbourne railway yard, and to the west of, and close to, the River Lea. It is in line with the Nazeing channel, the nearest known point of which is only 300 yds. distant (G.R. 52/381(5)072), on the opposite side of the Lea.

'During 1947 and 1948 the pit showed a peat-filled channel up to twelve feet deep to the bottom of the peat. The lower part of the peat was much decayed, and resembled the Boreal peat of the Nazeing channel: a sample of the base of this peat was sent to Dr. Godwin.

'The lower few feet of the peat was locally rich in shells, including *Helix nemoralis* which is also common in the Boreal peat of the Nazeing channel. At the lowest part (under the peat) there was a bed of brown loam with shells, up to eighteen inches thick. Below this, and extending farther under the peat, there was a foot or two of sand with rolled peat, hazel nuts, shells and bones.

'The upper foot or two of the underlying gravel had been rearranged in the bed of the channel, and rendered highly calcareous by the extensive development of calcareous algae. A large number of the stones were coated to varying degrees by the calcareous deposit, and there were many where this had developed into concretions up to twelve or fourteen inches in diameter. All these deposits were variable and irregular, and at one spot the rearranged gravel packed with algal concretions was four feet thick, and went down nearly to the floor of Reading beds; this evidently filled a scoured-out hollow in the bed of the channel.

'The great majority of the concretions approximated to the spherical in form, and even the large "cannon-ball" examples often had a surprisingly small stone in the middle. I saw one of a more fan-shaped form which had developed only one way from the underlying stone, but usually the stone was near the centre, so I presume that these must have been turned about from time to time.

'From the general appearance of the deposits, and from the situation, it s possible that this channel may be closely associated with the later stages of the Nazeing channel (*Phil. Trans.*, 1952, 169). On the other hand, no race of such concretions was seen in the Nazeing deposits.

'It is unfortunate that I was unavoidably prevented from doing as much work in this pit as I could have wished, but I have a collection of the Mollusca, a horn-core of *Bos primigenius*, since sent to the British Museum (Natural History), and part of an antler of Roe Deer. The occurrence of bones was another difference from the Nazeing deposits in which remains of Mammalia were extremely rare.'

It appears from the section that two sequences are involved, the first consisting of Beds 3 and 4 (so numbered by the present author) and the other, which cuts into the first, consisting of Bed 5 and subsequent beds. The earlier phase would be the 'scoured-out hollow' of Mr. Warren's account. The following is a list of the beds with the numbering now adopted:[1]

9. Soil and Marsh Clay with *Unio* in places
7. Peat (including sandy beds with shells)
6. Decayed Peat
5. Brown Loam
4. Sand with Hazel nuts, etc.
3. Rearranged gravel with algal concretions
2. Gravel of the Ponders End Stage
1. Reading Beds

Five samples of shelly deposits were examined in the material presented to the British Museum (Natural History). In addition a few shells were still in the possession of Mr. Warren and were given to the author. The museum material still bears Mr. Warren's original labels as follows:

Sample 5. 'Bottom of peat . . . overlying the marly gravel with algal concretions' (Bed 6 of the above sequence).
Sample 4. 'Lenticular bed of clay below peat. . . .' (Bed 5).
Sample 3. 'Sandy bed with lumps of peat, below the peat. . . . This bed overlies the marly gravel with algal concretions' (Bed 4).
Sample 2. 'Calcareous top of gravel (rearranged) with algal concretions' (Bed 3).
Sample 1. 'Inside of horn core of *Bos primigenius* found below the peat. . . .' (Bed 3 of this sequence).

It is proposed to defer giving a full faunal list from the various samples but certain facts can be used to test the validity of the sequence established in the previous sections of this paper.

The material from Bed 3 and Bed 4 is exactly comparable with that of the Rammey Marsh channel, both as regards its shell fauna and as regards its lithological characters. Some grey calcareous concretions which Mr. Warren possesses are indistinguishable from concretions of a like kind from Bed 3 of Rammey Marsh. Shells were incrusted with calcareous material in the same manner and the faunas were similar. The shells from within the horn-core from Bed 3 were stained brown and many of them were encrusted. There were also small rootlet-concretions, similar to those of the other site. *Planorbis albus* was common in this sample, but no *P. acronicus* were found. *Physa fontinalis*—good, large shells—were common but this is attributed to the protection which the horn-core afforded to this fragile shell. The author has noticed a similar abundance of this species in other sheltered conditions. Bed 4 had rare examples of *Bithynia leachi* and a dozen or more of *Planorbis acronicus*.

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[1] The omission of a Bed 8 is due to the fact that the present author has done further work on the site which he hopes to publish at a later date.

Bed 5 and Bed 6 were, however, quite distinct. Although they bore a strong resemblance to the fauna of Carthagena Lock channel the shells are not absolutely identical. *B. leachi* is rare in both beds. *P. acronicus* is represented by a single specimen in Bed 6, probably derived. It must be remembered that the Carthagena Lock deposit is a current-bedded torrent deposit containing material sorted from other beds which had been destroyed by the river. The relative frequency of the shells has no biological significance. Although *Bithynia leachi* is less common than at Carthagena Lock, there are other indications that the two beds are of approximately similar ages. *Aplecta hypnorum*, not yet recorded from Rammey Marsh but of which two specimens have so far been found in the later deposit, was found also in Bed 5. Furthermore the shells are clean and contain none that are encrusted with lime. It is therefore suggested that these two beds may represent the 'bed of unknown age' referred to in Phase 11 of the relative chronology already suggested.

Thus the evidence of this new section demonstrates by superposition the sequence of events already proposed on the basis of other facts. It also proves what was argued indirectly, that at various times the river did cut through and destroy some of its earlier deposits, including the Rammey Marsh channel whose lime-encrusted shells are frequently found incorporated in later deposits. It also shows that in spite of appearances, and the proximity to Mr. Warren's older sections, the peat which fills the channel cannot be as old as the Boreal peat and is almost certainly considerably younger than the Atlantic peat.

As stated in his note, Mr. Warren was unable to give more than a brief examination of the section at the time, and his collections of shells from the lower beds are larger than those from the upper ones. In the summer of 1954 the author identified the section, though the lower horizons were entirely flooded. In addition the upper beds showed a significant difference, on account of which the site warrants a fuller description which the author hopes to offer at a later date.

ACKNOWLEDGMENTS

The author is indebted to the following bodies or their representatives for permission to visit sites and to publish this report: Harlow Development Corporation; Middlesex County Council; Messrs. J. D. & D. M.

Watson and their resident engineers; The Twickenham Gravel Company; Messrs. R. & A. Main Ltd., and the Explosives Research and Development Establishment. He also wishes to thank the Keeper of the Department of Palaeontology, British Museum (Natural History), and his staff for allowing access to the material in their charge; a number of former pupils who assisted in some of the routine work in laboratory and field; Mr. P. C. Lodge for photographic assistance; Dr. J. P. Harding and Mr. D. E. Kimmins for advice on the ostracods and the caddis flies respectively; and Mr. S. H. Warren for cordial co-operation at all times. Finally, Mr. A. G. Davis has frequently accompanied the author in the field and has reciprocated by showing him those sites in the Thames Valley in which he (Mr. Davis) is specially interested. He has always supplied lists of any faunal material collected by him in the Lea Valley and these have agreed with the author's own lists in all but the very rarest species. In such cases the tables in this paper combine the two.

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DISCUSSION

DR. G. H. DURY said that in the Ham River Company's working at Fisher's Green—a site in the midst of Dr. Hayward's localities—there has been exposed, from time to time, a magnificent section through an old channel. The fill is of peat, which occupies a channel cut in flood-plain silt and descends to the Flood Plain Terrace gravels below. In the same pit mammalian bones have been collected in quantity, mainly by Messrs. Whitten and Raine and their students from Kingston Technical College. Also in this pit the calcareous layer is very well-developed indeed.

In this connection I should like to refer Dr. Hayward to the remarks made by H. J. O. White, in his description of the fill of the Kennet Valley, as given in the Hungerford & Newbury Memoir (1907). Calcareous material is recorded from that district; I have also encountered it myself in various valleys in the Cotswolds, where undoubtedly it forms part of the fill of abandoned channels. However, the channels of the Cotswold valleys are the former beds of rivers which are now underfit (cf. the speaker's account of underfit streams in *American Journal of Science*, 1954), and the deposition of peat and of calcium carbonate seems to be associated with changes in discharge. I should like to ask Dr. Hayward if he has considered the evident fact that the Lea, too, is a misfit stream—its heads above Ware display meandering valleys, and the lower part of the trunk stream appears to have undergone shrinkage, to judge by the probable pattern of meanders before artificial straightening took place. In the interpretation of the sections described by Dr. Hayward, account ought to be taken of the considerable changes of volume which may safely be inferred, and also of the tendency shown by any meandering stream to sweep over its flood-plain.

DR. HAYWARD, in replying to Dr. Dury, wrote as follows (Dec. 1956):

'The pit at Fisher's Green, to which Dr. Dury introduced me, has proved very important. Two channels are visible in the pit, the one referred to by Dr. Dury being the local equivalent of the channel studied at Rammey Marsh. The other I correlate with part of the sequence at Nazeing originally described by Mr. S. Hazzledine Warren. Here the later channel does not cut into the deposits of the earlier one.

'I am indebted for the reference to the Newbury area and agree that probably the parallel is not a mere coincidence. At the time the present paper was written the sole aim was stratigraphical, but in the interim more general matters have been considered, and these have included some of those mentioned by Dr. Dury.'

The Croxteth Park Inlier, near Liverpool

A Re-examination of Certain Fossiliferous Horizons in the Lower Coal Measures and Millstone Grit[1]

by R. M. C. EAGAR and W. H. C. RAMSBOTTOM

Received 3 January 1955

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ABSTRACT: Re-examination of the available cores of Gillmoss and Finch Farm borings, described by Hickling (1916), confirms his correlation between the boreholes but indicates that approximately 500 ft. of strata, previously regarded as belonging to the Lower Coal Measures, should be assigned to the Namurian. The Bunter Sandstone apparently lies directly on 300–400 ft. of reddened beds of the Lower Coal Measures. The latter seem to be almost complete at Croxteth Park where they reach a thickness of 1000 ft. There is a decrease of 200 ft. in their thickness on passing south-westward from Skelmersdale to Croxteth Park. This decrease takes place mainly in the middle third of the Lower Coal Measures and is accompanied by a deterioration in the degree of development of the coal seams.

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1. INTRODUCTION

CROXTETH PARK lies between the Liverpool suburb of West Derby and Knowsley, five and a half miles north-east of Liverpool Central Station and just south of the East Lancashire Road which links Manchester and Liverpool (Figs. 1, 2).

It has long been known (Hull, 1860, p. 6) that a small area of Coal Measures, surrounded by red rocks, underlies the vicinity of the Park, to form the westernmost exposure of the Lancashire Coalfield. Shortly before 1915 Garswood Hall Colliery Company put down two exploratory borings to prove the area. The first, Finch Farm (Fig. 2, south-east corner), was situated immediately opposite the end of Mab Lane, a quarter of a mile north of Finch Farm and about 800 yds. south-east of Finch Lodge. The second, Gillmoss (Fig. 2, north-west corner), lay 150 yds. east of Gillmoss Chapel and 400 yds. north-west of Gillmoss Lodge. The borings proved no coals of economic value and reached what was believed to be Millstone

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[1] Published by permission of the Director, H.M. Geological Survey.

Grit at about 1500 ft. (Fig. 3, sections 1 and 2). They were abandoned after a further few hundred feet, on the advice of the late Professor G. Hickling, who was consulted only when this stage had been reached. Hickling made a brief examination of the cores, sent a selection of them to the Manchester Museum, and subsequently wrote an account of the borings (1916).

Between the boreholes at Finch Farm and Gillmoss Hickling established a correlation based essentially on certain similarities in the lithological succession. Using also palaeontological evidence in the Carboniferous beds he classified the measures at Croxteth Park as follows:

	Finch Farm feet	Gillmoss feet
Drift	33	32
Trias	—	247
Permian Marls	222	313
Lower Coal Measures	1273¾	1243
Millstone Grit	272¾*	435

Mainly from the evidence afforded by these borings Hickling deduced he general structure of the area, and subsequently his views were confirmed by mapping carried out by H.M. Geological Survey in 1930. It appears that he Lower Coal Measures rise to form an elongate semidome with axis rending NW.–SE. through Croxteth Park. On all sides except the south-west, where the structure is terminated by the Croxteth Fault, the measures are overlain by red rocks (including Lower Mottled Sandstone), without visible discordance of dip. To the south-west, across the Croxteth Fault, Lower Coal Measures are assumed to lie beneath downfaulted Triassic sandstone.

In view of the possibilities of the structure as an oil trap, Mr. E. S. Pinfold, of the Oil Department, Messrs. Steel Brothers, considered the area worth further investigation.[1] One of us (R.M.C.E.) was asked to re-examine the selection of cores from Finch Farm and Gillmoss boreholes and to prepare a report. We are grateful to Messrs. Steel Brothers who have generously permitted us to publish the main facts contained in the report. Also we are indebted to the late Professor Hickling who kindly confirmed ertain details concerning the collection and documentation of the cores, nd to Professor S. E. Hollingworth who helped us to discover further npublished records of the holes.

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* Reference to Hickling's sections indicates that the figure of 372¾ given by Hickling (1916, . 272) is an error. Moreover, we are indebted to Capt. J. H. Williams, of Croxteth Estate Office, ho has kindly shown us records indicating that Finch Farm borehole was continued to a depth f 1884 ft. and Gillmoss to 2517 ft., additions of 92 ft. and 247 ft. respectively to the sections ecorded by Hickling (1916, pl. V). These additions are shown in Fig. 3, below the arrows on sections and 2.

[1] A new borehole has since been sunk west of Croxteth Hall at the site shown on the map Fig. 2). The boring crossed the Croxteth Fault at 1663 ft., and at 1682 ft. the core yielded *Anthraconaia* (?) aff. *bellula* (Bolton), suggesting an horizon not far below the base of the Rough Rock. See D. Magraw & W. H. C. Ramsbottom. A Deep Borehole for Oil at Croxteth Park, near iverpool. *Liv. and Manch. Geol. Journ.*, 1 (6), 512.

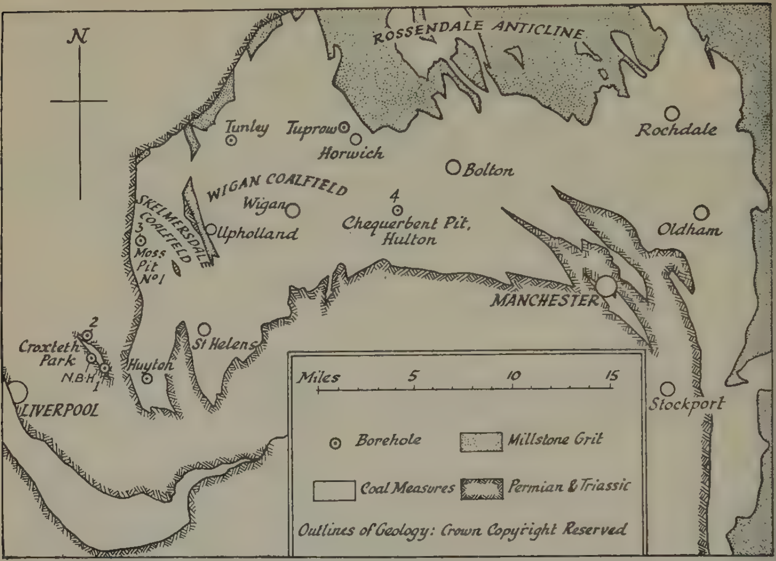

Fig. 1. Sketch-map of the southern Lancashire coalfields showing the Croxteth Park inlier. Numbers at certain boreholes refer to correspondingly numbered sections in Fig. 3. N.B.H. = new Croxteth borehole. (Based on maps of H.M. Geological Survey, by permission of the Director)

We believe that in the light of recent work on the Lower Coal Measures (e.g. Jones & others, 1938; Eagar, 1951), there is sufficient independent evidence based on marine fossils (examined by W.H.C.R.) and non-marine fossils (examined by R.M.C.E.), to confirm Hickling's correlation between the boreholes of Finch Farm and Gillmoss. But the fossil evidence suggests a considerable revision of his tentative classification of the rocks penetrated.

2. RE-EXAMINATION OF THE FOSSILIFEROUS HORIZONS COLLECTED BY HICKLING

All the available material is preserved in the Manchester Museum. At Finch Farm (Fig. 3, section 1) and at Gillmoss (Fig. 3, section 2) fossiliferous horizons recorded by Hickling may be revised as follows:

DEPTH AND HORIZON	FINCH FARM
At 908 ft., above 10 in. coal	*Elonichthys* sp., *Lepidodendron* sp.
At 1022 ft.,[1] above 11 in. coal	*Gastrioceras subcrenatum* C. Schmidt, G. sp. nov., *Dunbarella papyracea* (J. Sowerby), *Posidoniella* cf. *multirugata* Jackson.

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[1] This figure was erroneously written as 1122 ft. by Hickling (1916, p. 271). All available evidence, including Professor Hickling's unpublished notes, supports this correction.

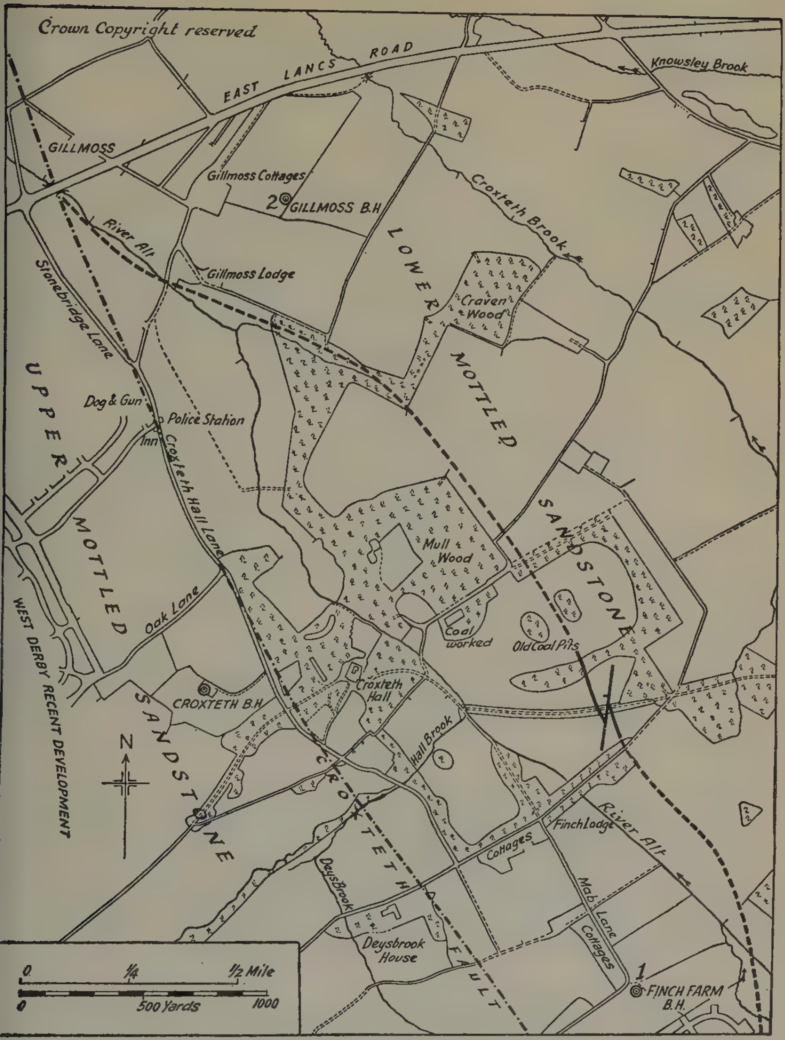

Fig. 2. Sketch-map of part of the Croxteth Park area, based on Geological Survey ix-inch sheets Lancashire 106 NE., and 107 NW., with modifications. (By permission f the Director, H.M. Geological Survey.) For a revision of the estimated position of he Croxteth Fault we are indebted to Messrs. Steel Brothers

DEPTH AND HORIZON	FINCH FARM
At 1297 ft., above sandy shale and siltstone	*Gastrioceras cumbriense*? Bisat, Orthocone nautiloid, *Elonichthys sp.*
At 1529 ft., above 9 in. coal	Palaeoniscid fish scales, *Sternbergia* sp.
	GILLMOSS
At 975 ft., above 2 ft. 3 in. coal with thick fireclay	Hickling recorded fish scales, but his specimens have not been found.
At 1087 ft., 46 ft. above 6 in. coal	*Carbonicola sp.* of the *C. fallax* group—small forms with large H/L ratio such as typically occur in the Bassy Mine succession at high levels in the cyclothems (Eagar, 1952).
At 1132 ft., up to 1 ft. 4 in. above 6 in. coal	*Carbonicola* aff. *limax* Wright (cf. Eagar, 1947, Fig. 14k), *C.* cf. *artifex* Eagar, *C. pilleolum* Eagar and *C.* aff. *pilleolum*—forms typical of the lower cyclothem of the Soft Bed–Bassy Mine succession. *Rhizodopsis sauroides* (Williamson).
At 1261 ft., above 2 in. coal	*Orbiculoidea* cf. *nitida* (Phillips), *Lingula mytilloides* J. Sowerby, *Dunbarella papyracea* (J. Sowerby), *Gastrioceras subcrenatum* C. Schmidt, *Gastrioceras* sp. nov. There can be little doubt that this fauna is on the same horizon as that found at 1022 ft. in Finch Farm borehole.
At 1266 ft., immediately above 2 in. coal	*Elonichthys aitkeni* Traquair.
At 1834 ft., above sandy shales and siltstones	*Lingula mytilloides* J. Sowerby, *Elonichthys aitkeni* Traquair, *Rhizodopsis sauroides* (Williamson), *Rhabdoderma elegans* (Newberry).
At 1835 ft.	*Sigillaria* sp.

Professor Hickling (*in litt.*) has stressed that his examination and collection of the material from the cores were made very quickly and that therefore his collections should be regarded rather as samples of some of the fossiliferous horizons than as complete records. Thus in the collections at Manchester Museum absence of fossil material cannot be regarded as evidence that no fossils occurred at a particular horizon.

3. CORRELATION BETWEEN THE BOREHOLES OF FINCH FARM AND GILLMOSS

Originally the boreholes were correlated on a lithological basis. The sections proved to be similar to one another in their middle parts where three coals, of which the upper is associated with an unusually thick fireclay, are separated by the same intervals of shale. Hickling (1916, p. 270) also noted that the grits, each 103 ft. thick, near the base of the sections

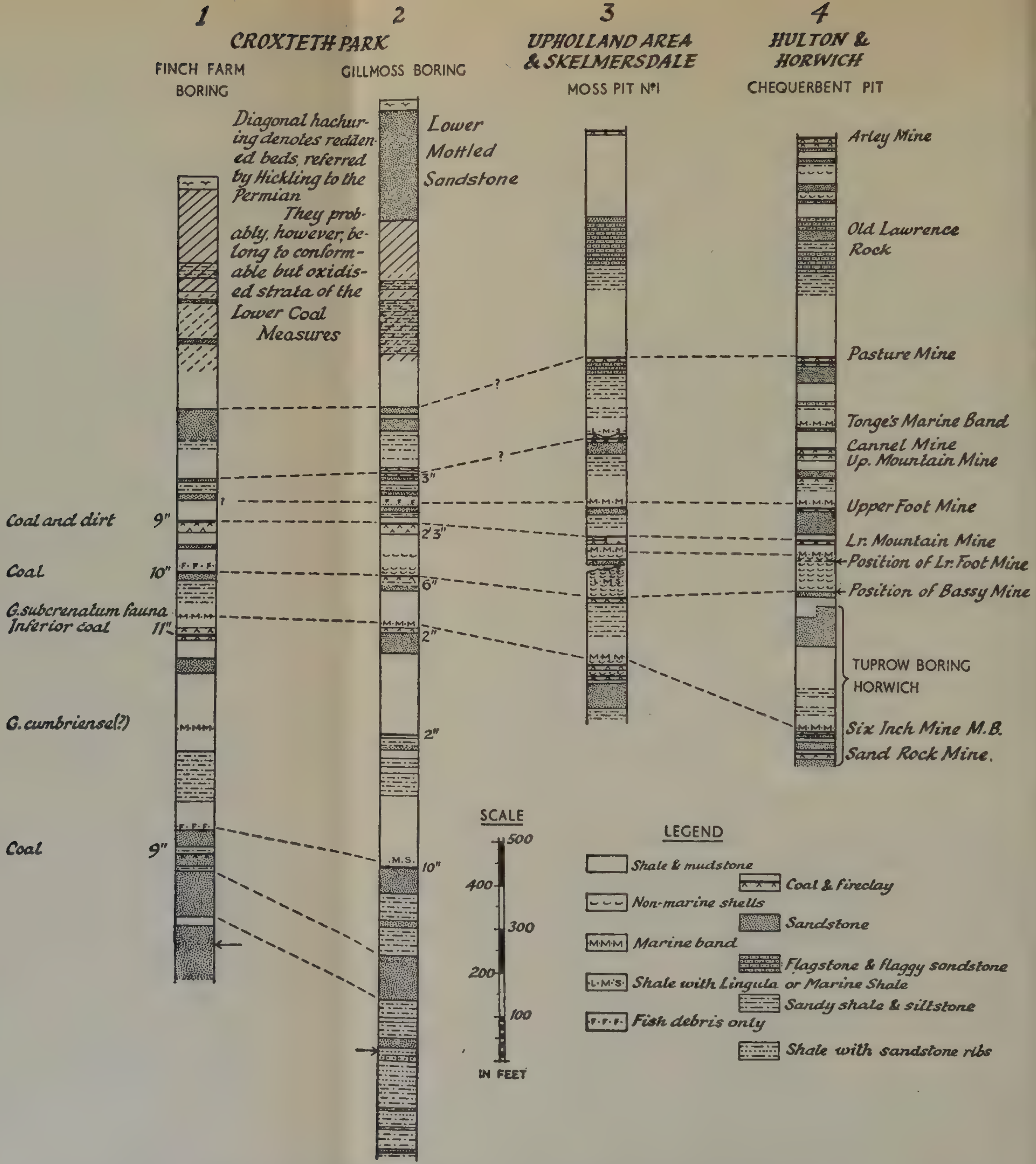

Fig. 3. Borehole sections at Croxteth Park (Sections 1 and 2) correlated with measures in west and central Lancashire (Sections 3 and 4). Diagonal hachures in Sections 1 and 2 denote predominantly red beds; broken hachures denote measures in which grey beds are developed appreciably. Sections 1 and 2, to depths of 1791 ft. 6 in. and 2270 ft. 2 in. respectively, shown by arrows, after Hickling (1916, p. 272, pl. v), the remainder from journals of the borings at Croxteth Estate Office; Sections 3 and 4 after Eagar (1951, pl. i), based on Jones *et al.* (1938, pl. ii). Sections 1 and 2 are corrected for dip. In Section 4 it is not certain that the record of the Tuprow Boring, Horwich, is correctly added to that of Chequerbent Pit

To face p. 69]

were also identical in character. Hickling's correlation (Fig. 3, broken lines between sections 1 and 2) receives confirmation from the marine faunas at 1022 ft. at Finch Farm and 1261 ft. at Gillmoss, which also appear identical. Making this correlation we then have:

(a) *Lingula* and fish scales at 1834 ft. at Gillmoss represented by fish scales at 1529 ft. at Finch Farm.
(b) No representative at Gillmoss of the marine band at 1297 ft. at Finch Farm.
(c) Non-marine shell horizons and fish scales at 1132 ft. and 1087 ft. at Gillmoss represented only by fish scales at Finch Farm.

The difficulties of (b) and (c) may be met by assuming that the collections are incomplete. In the lowest third of the sections there appears to be south-eastward thinning from Gillmoss to Finch Farm.

4. CORRELATION OF THE CROXTETH PARK SEQUENCE WITH MEASURES OF THE LANCASHIRE COALFIELD

The faunas at 1022 ft. at Finch Farm, and at 1261 ft. at Gillmoss, strongly suggest the *Gastrioceras subcrenatum* marine band which overlies the Six Inch Mine at which the base of the Lower Coal Measures is drawn in Lancashire. The shell faunas at 1087 ft. and 1132 ft. at Gillmoss are typical of the Soft Bed–Bassy Mine succession (Eagar, 1952). The correlation indicated by the broken lines between sections 2 and 3 of Fig. 3 was in fact reached independently by the two authors, on the basis of marine and non-marine evidence. Comparison of the remaining parts of these sections brings out further points of similarity between them. The main coal of the Gillmoss section, 2 ft. 3 in. thick and overlying nearly 30 ft. of fireclay with shale, is correlated with the Lower Mountain Mine of the west Wigan sequence (= 'Middle Mountain Mine' of Ravenhead Brickworks, Upholland; see Eagar, 1951, p. 41), a coal overlying a 12 ft. fireclay in which a thin coal, the Rambler Mine, is locally developed (Jones *et al.*, 1938, p. 132). The succeeding 3 in. of coal of Gillmoss and 6 ft. of fireclay lying 4 ft. above it, then represent the Upper Mountain and Cannel Mines, which are just separated by mudstone of the same thickness at Bispham Hall Brickworks, Upholland (now flooded) and are recorded as similarly separated at Moss Pit No. 1, Skelmersdale (Fig. 1; Jones *et al.*, 1938, p.134, and pl. ii, p. 14). In the lower part of the succession, the marine band containing a poorly preserved specimen of *Gastrioceras cumbriense*? Bisat occurs at the expected horizon in the Namurian, the *G. cumbriense* marine band. Indeed, the lowest *Lingula* band at Finch Farm may possibly lie on, or near, the *G. cancellatum* marine band. Thus, at Finch Farm just over 700 ft. of strata should be assigned to the Millstone Grit (Namurian) instead of 273 ft., as suggested by Hickling, and at Gillmoss there are just under 1000 ft. of Millstone Grit instead of 435 ft. Further boring, unrecorded by Hickling, increases the thicknesses of Millstone Grit to 800 ft. and nearly 1250 ft. respectively (see footnote, p. 65).

The absence of the Bullion Mine Marine Band from the Croxteth records and material is difficult to understand, for the band is thick and richly fossiliferous in the Upholland area and one would hardly expect a similar development to be missed in the Croxteth cores. It should be noted, however, that the appropriate horizon has yielded fish scales at Gillmoss, while at Finch Farm neither fossils nor the preceding coal, fireclay or sandstone have been found. In fact at Gillmoss the supposed horizon of the Marine Band lies between two sandstones. If, therefore, this band has not thinned out westwards in passing into dark shales yielding fish scales,[1] it is conceivable that it may have been cut out from above by a sandstone. The Bullion Mine Marine Band may be seen in a position comparable to that which it occupies at Croxteth in the Tunley Borehole section, Wrightington (Eagar, 1951, p. 27, fig. 3, section 2), where it has been almost engulfed by the overlying sandstone.

As the Lower Foot Mine is absent, or is represented by a fireclay, at Upholland, its absence at Croxteth is not remarkable. The overlying marine band is thin at Upholland, and lies in shales which are not appreciably different from those lying about and below it, so that it may well have been missed in the borings at Croxteth.

Further details of the new correlation must be speculative. Since the lowest main coal at Finch Farm lies apparently 45 ft. below the *G. subcrenatum* Marine Band, this coal is more likely to be the Sand Rock than the Six Inch Mine. Failure of the Six Inch Mine north-west of Wigan, where the Sand Rock Mine is well developed, has been noted recently by one of us (Eagar, 1951, p. 23).

In short, apart from minor points in the preceding paragraphs, the new correlation does not involve serious stratigraphical problems. There appears to be a general and fairly even thinning of the measures, deterioration in the development of the coals, and probably also of the fossiliferous horizons, on passing south-westward from Skelmersdale to Gillmoss. A further thinning, of the Namurian only, is apparent from the latter south-eastwards to Finch Farm. Somewhat similar changes in the development of the Lower Coal Measures have been reported by Trotter (1954, p. 62) when they are traced in deep borings round the southern margin of the Lancashire and Cheshire coalfield.

5. THE RED BEDS OF CROXTETH PARK

The sandstone at the top of the Gillmoss borehole appears to be referable to the Lower Mottled Sandstone. Hickling records the underlying measures at Gillmoss, and their presumed equivalents at Finch Farm as predominantly red in colour, but include variegated 'marls' and black bluish-grey and brown shales. They have not yielded fossils and unfortunately no samples of them now remain in the collected cores. Hickling considered the upper part of these beds to belong to the Permian whereas H.M. Geological Survey mapped them as possibly referable to the Ardwick Series of the Upper Coal Measures. However, the recent work of Trotter (1939, 1953, 1954) has shown very similar red bed development which may be found to a depth of several hundred feet below a Triassic cover in Carboniferous shales of very different ages. In south Lancashire and Cheshire (Trotter, 1953, pl. xiv, fig. 1) beds of this type were found directly beneath the Trias on horizons above and within the Productive Coal Measures; they are characterised by an upper zone in which reddening is almost complete and a lower zone in which only partial oxidation has taken place, with resulting inclusion of grey beds. Examination of Hickling's records of the Croxteth borings indicates a similar distribution of degree of oxidation, represented (in Fig. 3) by diagonal hachures which are broken in the lower zone. In fact these red and variegated beds may belong to the Lower Coal Measures, as Dr. Trotter has pointed out to us in conversation. This view is strengthened by a consideration of the general sequence occurring above the horizon, or supposed horizon, of the Pasture Mine in the four sections shown in Fig. 3. In every section a thick mudstone group of about the same thickness is followed by a group of thick flaggy beds, again of equal thickness, followed by predominantly shaly measures. If these lithological groups are correlated with one another, then almost the entire thickness of the Lower Coal Measures is present beneath Croxteth Park. Therefore we suggest the following tentative revision of the classification of the Croxteth Park sequence, allowing corrections for the dip of the beds in each hole and adding the basal sections unrecorded by Hickling:

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[1] The Bullion Mine Marine Band is known to fail, locally, at Royton near Oldham (Tonks *et al.*, 1931, p. 31).

	FINCH FARM		GILLMOSS	
	feet		feet	
Drift	33		32	
Lower Coal Measures	1008	(of which 420 ft. are partially oxidised)	935	(of which 320 ft. are partially oxidised)
Millstone Grit	810+		1222+	

If the Lower Coal Measures are almost complete beneath their Triassic cover, as suggested by the sections in Fig. 3, then there is a decrease of about 200 ft. in their thickness on passing westward from Skelmersdale to Croxteth. This decrease takes place mainly in the middle third of the Lower Coal Measures, where the better coal seams are usually found, and is accompanied by deterioration in the degree of development of these coals.

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The Dislocated South-Western Margin of the Insch Igneous Mass, Aberdeenshire

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Received 15 November 1954; read 2 December 1955

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ABSTRACT: The natural contacts of the great Insch igneous mass are roof, and the exposed igneous rocks may form only a small part of a much greater body. The south-western portion of the contact is a mechanical one, however, along which considerable upward movement of the adjacent country-rocks relative to the igneous rocks has led to the removal of the thermal aureole, to intense dislocation-metamorphism and lenticularisation of the igneous and country-rocks, and to the emplacement of tectonic pods of serpentine and calc-silicate rocks coming from depth. Over great parts of the whole Insch mass the igneous rocks show comparable dislocation effects, with silicification and amphibolitisation in appropriate rocks, increasing towards the south-western contact shear-zone. Such effects are concentrated within the igneous body itself along two intense shear-belts aligned with the main contact dislocation. All dislocations are later than all the igneous rocks belonging to the Insch intrusion.

1. INTRODUCTION

THE INSCH igneous mass, the largest of the post-metamorphic basic intrusions belonging to the gabbroic province of north-east Scotland, has an elongated outcrop some twenty miles in east–west length and averaging four miles in width. Recently Sadashivaiah (1954) has discussed the form of the intrusive body and has concluded that the natural contacts on the northern, eastern and southern sides are roof. The western portion of the southern contact appears not to be a natural one, however. In the region between the Bennachie Granite and the Bogie outlier of Old Red Sandstone (Fig. 1) the contact is formed by a steep belt of dislocation in which movement has been responsible for the disappearance of the thermal aureole, the emplacement of tectonic pods of serpentine and a general cataclasis and mylonitisation. Earlier Read (1951) had shown that in the eastern part of the southern contact mylonitisation and related processes were widespread, especially affecting post-gabbro acidic dykes. The much more violent phenomena found farther west are the subject of this present paper in which is also considered the dislocation-metamorphism of the igneous rocks of the whole of the Insch intrusion.

The part of the Insch mass and its contact here dealt with was described by L. W. Hinxman & J. S. G. Wilson in the *Geological Survey Memoir* (Central Aberdeenshire) published in 1890 to accompany Sheet 76 of the 1-inch Geological Survey Map of Scotland. The serpentine lenses so prominent at the contact (see Fig. 2) were correlated with the peridotites of the Bourtie area recently described by Sadashivaiah (1954). In fact the two groups are geologically distinct. A narrow zone of mica-schist was shown on the 1-inch map as occurring between the igneous rocks and the andalusite-schists which form the country-rocks and thus an impression of a contact aureole of some kind may have been conveyed. It is shown in this present paper that these mica-schists are regional andalusite-schists affected by strong dislocation-metamorphism.

As has been mentioned, the country-rocks of the Insch intrusion near the south-western contact are andalusite-schists, belonging to the Dalradian Series, of a facies developed very widely in north-east Scotland (Read, 1955). Olivine-gabbros, with their derivatives, and hypersthene-gabbros are the principal components of the Insch mass. The former types occupy most of the northern part of the mass and approach the south-western contact zone only around the Hill of Johnston (Fig. 2). Between the Bennachie Granite and Knockespock House, mostly hypersthene-gabbros lie next to the country-rocks. As already noted, a number of lenticular masses of serpentine occur at or near the contact in this region. To the west of Knockespock House, granites and diorites, belonging to a contaminated acid intrusion of post-gabbro date which forms the west end of the Insch Mass (Sadashivaiah, 1954a), intervene between the hypersthene-gabbro and the country-rocks; a lenticular body belonging to this late group is found north of Charleston. These younger and more acid rocks have been affected by the dislocations here described.

Because in field-exposures, in hand-specimens and in thin sections, all the rocks along the south-western contact zone show evidence of strong disturbance, this zone may be called the *south-western contact shear-belt*. Two to three miles north of this zone, two east–west belts of special shearing traverse the gabbros (see Fig. 1). The more northerly is seen around

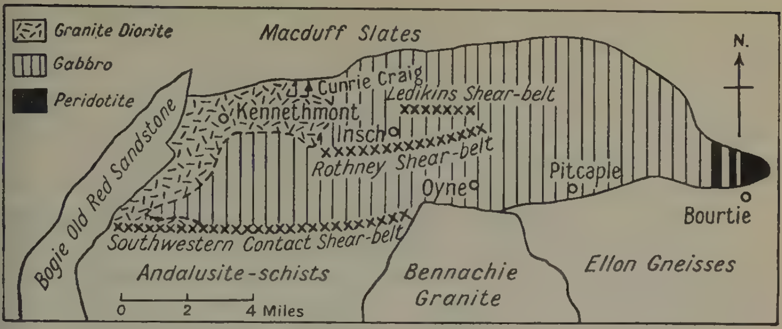


Fig. 1. The Insch Igneous Mass, showing location of main shear-belts

Ledikins and may be referred to as the *Ledikins shear-belt*. The second and more important one runs into the valley of the Shevock immediately west of Insch. This is well seen in Rothney quarry, near Insch, and will be termed the *Rothney shear-belt*. In addition to these three parallel belts of dislocation, other minor shear-zones are widespread in the gabbros.

2. THE SOUTH-WESTERN CONTACT SHEAR-BELT

The characteristic features throughout the contact zone between the Bennachie Granite and the Bogie outlier are the lenticularity of the different bodies of rock, the prevalence of cataclasis and disturbance in the whole contact belt and the absence of hornfelsing in the country-rocks. The description of the contact belt which follows is given in sections from east to west. The localities mentioned, and the distribution of the rock-types, are shown in Fig. 2.

(a) **Parkbrae and Easter Newton.** Abnormalities begin against the Bennachie Granite south of Parkbrae. Here crushed and sheared gabbros,

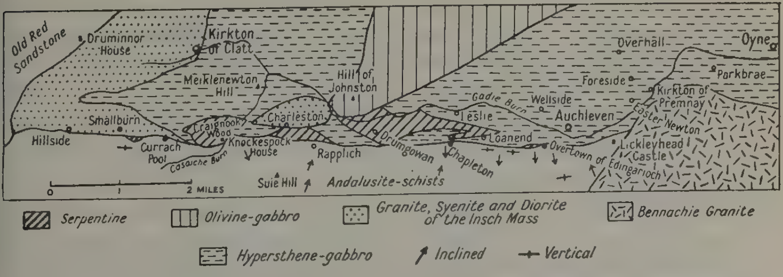


Fig. 2. Geological map of south-western contact of the Insch Igneous Mass

with shear-planes running east and west parallel to the gabbro contact, occur against the granite and, in one locality, a small lens of slickensided serpentine intervenes between the gabbro and granite but its actual relation to these rocks cannot be seen. Another small body of serpentine is exposed in a quarry at Easter Newton where a steep mechanical contact running east and west between sheared gabbro and slickensided serpentine is exposed. Like the contact, slickensided surfaces in the serpentine and shear-planes in the gabbro run east and west. The gabbro has been dragged up to the south on a pile of shear-planes. These two clearly exotic lenses of serpentine serve to introduce the phenomena seen on a much greater scale farther to the west.

(b) **The 'Slug Road' and Overtown of Edingarioch Area.** Astride the road (the Slug Road) leading from Auchleven over the hills to Donside, a number of scattered outcrops of rocks of the contact zone are available. On the higher slopes of the contact hills south-west of Lickleyhead Castle, andalusite-schists are seen, inclined steeply to the north or south. Northwards towards the contact, around Overtown of Edingarioch and immediately to the west thereof, the country-rocks are sheared thin platy mica-schists and pebbly grits, the parting planes running vertically east and west. Due west of Overtown, a small serpentine lens comes between rotten gabbro and these sheared mica-schists; pink granitic material, intensely slickensided, is found in the sheared melange immediately south-west of the farm buildings.

On the other side of the Gadie Burn in the large quarry at Wellside, two thirds of a mile north-west of Auchleven, spectacular dislocations are seen. Here dozens of great shear-planes are well exposed and along them the gabbro has been brecciated, ground down into whitish material and mylonitised. Streaks and lenses of various kinds of deformed rock are developed. One great lens, 50 ft. by 30 ft., is found to be made of banded basic granulite, consisting of bands rich in pyroxene or olivine or felspar or pyroxene–biotite–hornblende, which bears a considerable resemblance to the olivine-hornfelses described by Sadashivaiah (1950) from the northern unmoved contact of the Insch intrusion at the Shevock and Scotstown. The melange exposed in the quarry is made up of a pile of lenses of gabbro and basic granulite or hornfels packed up by steep thrusts which are dipping at angles of about 45° between west and north.

(c) **The Leslie Area.** The contact zone here is dominated by a serpentine body running east and west, mostly south of the Gadie Burn. This serpentine is well exposed south of Leslie Church, on Hawk Hill north of Loanend, and westwards over Bog Hill to Drumgowan. South of Hill of Johnston, in a quarry at the roadside at Mill of Johnston, a sheared contact between broken serpentine and sheared gabbro is particularly well exposed. Innumerable shear-planes traverse both rocks, with the development of much platy jointing, slickensiding and brecciation adjacent to them. Most of the shear-planes are vertical or steeply inclined to the north-west.

In the surface of the road leading from Leslie to Chapleton a continuous section is available; from north to south are seen sheared serpentine, epidote-chlorite rock derived from gabbro, broken amphibolite of similar derivation, epidosite and granitic rocks, followed by sheared serpentine again at the Cornmill. In thin sections the Leslie serpentine is often a beautifully sheared rock, always traversed by innumerable chrysotile veins. Eastwards, at Loanend, a calc-silicate granulite composed of calcite, diopside and plagioclase, was formerly worked. Thus this eastern part of the Leslie contact shows a sheared complex of gabbro, serpentine and metasediments. South of Chapleton and elsewhere, sheared platy schists, often knotted, run vertically east and west. It must be emphasised that these rocks are schists and not hornfelses, and in thin slice show augening and distortion of such country-rock minerals as cordierite and micas.

Some instructive sections are seen in the gorges on the northern edge of the State Forest south-east of Drumgowan. South of the Leslie serpentine there occurs rotten gabbro with balls, lenses and thick vertical bands of metasediments, especially common being calc-silicate granulites with diopside and tremolite. At the presumed main contact south-west of Drumgowan, a sheared and augened quartz–mica–gneiss is followed, farther south and away from the contact, by vertical slabby and slaty knotted mica-schists. Farther along the contact, calcareous granulites crop out east of Rapplich.

Features characteristic of this Leslie contact zone are the intense deformation undergone by gabbro, serpentine and country-rocks alike, the lenticularity and admixture of different rock-types and the vertical attitude of the sheared rocks in general. The frequency of calc-silicate granulites among the metasedimentary types at the contact is to be noted.

(d) **The Charleston Area.** Immediately north of Charleston, silicified, brecciated and mylonitised granitic rocks are exposed (Plate 5, C). South of the deformed granite body there occurs a long east–west lens of serpentine, similar to the Leslie rock. The hill-slopes farther south are now thickly planted and little rock can be seen: on Suie Hill debris of knotted andalusite-schist is abundant and an old quarry a quarter of a mile south of Rapplich exposes silvery schists with diaphthoretic planes. Evidence for dislocation in this part of the contact zone is provided mainly by the mylonitised granite.

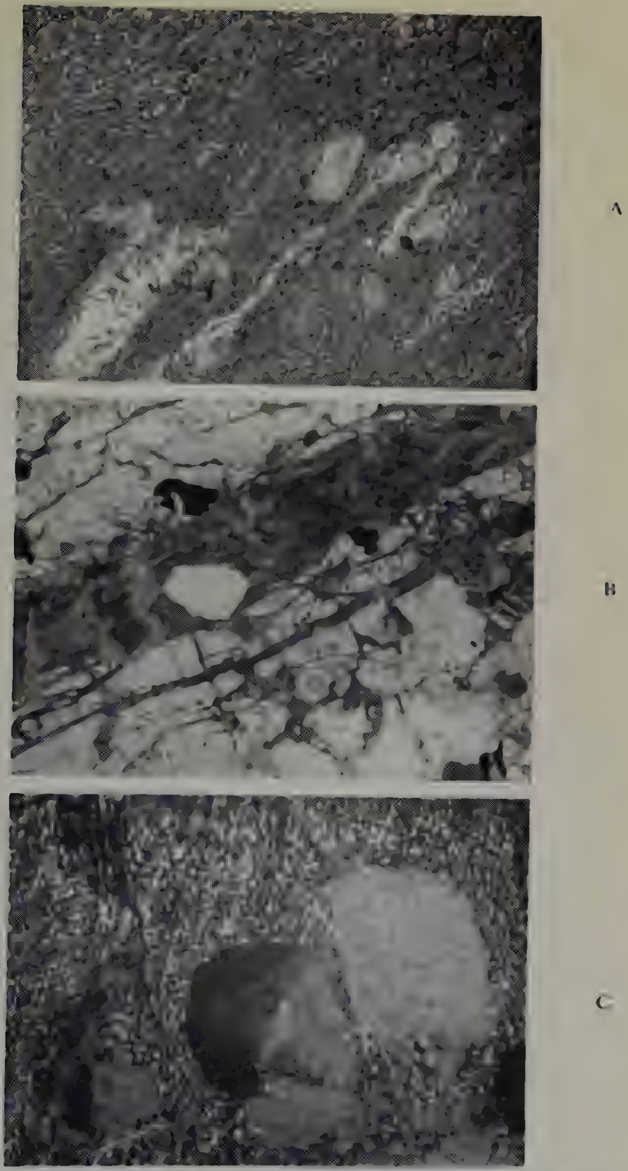
(e) **The Knockespock Area.** Phenomena allied to those already described continue farther westwards into the wooded ground about Knockespock House and beyond. Craignook Wood, immediately west of the House, is largely underlain by serpentine, crushed at the eastern end of its lens-shaped outcrop. Between this serpentine and the amphibolitised gabbro to the north there are found diopside–plagioclase–amphibole granulites, some of which are traversed by parallel fractures. The origin of these granulites is a matter of difficulty; they are not exactly like the metasedimentary calc-silicate granulites already noted, nor is sufficient field-evidence available to relate them to the gabbros—the question must be left open. Immediately west of Craignook Wood, around Currach Pool, important exposures are found. East of the Pool, near Mar's Lodge, an old opening shows a diopside-granulite made of large augen-groups of diopside crystals, set in a very fine-grained base of the same mineral (Plate 5, A); without question the rock can be interpreted as an originally coarse diopside rock that has been augened subsequently. Similar granulated and sheared calc-silicate rocks occur south of Currach Pool and here, too, a small band of serpentine makes it appearance. On the rising ground farther south and in Casaiche Burn, silvery mica-schists traversed by granulation belts are seen.

The Knockespock contacts repeat, with variations, the contact phenomena found farther east. Sheared gabbro, lensed serpentine and moved country-rocks, especially calc-silicate types, are again present.

(f) **The Hillside Area.** Westwards from Currach Pool, along the old track called Mar's Road, the rocks of the contact belt are only poorly exposed. On the hillslopes to the south there is much debris of andalusite-schist and a few outcrops show knotted schists and pebbly grits. Near the contact, south-east of Smallburn, calc-silicate granulites occur and show a slabby, almost slaty, structure. Immediately to the north is found a small lens of sheared serpentine and, farther north still, and within the Insch mass itself, is mylonitised granite. Few additional outcrops can be found till the western edge of the intrusion is reached. North of the contact and south-east of Druminnor House scattered exposures of dioritic rocks (Sadashivaiah, 1954a) show a good development of mylonitic bands. What is visible in the Hillside area is consistent with the general style of the south-western contact shear-belt.

3. DISLOCATION-METAMORPHISM OF THE INSCH IGNEOUS ROCKS IN GENERAL

In the south-western contact shear-belt the rocks affected by the dislocation processes include the country-rocks, the serpentine lenses, hypersthene-gabbro, granite and diorite, and certain minor acid veins intrusive into the gabbros. Of these groups the modifications of the first two have received incidental mention in previous pages and do not require fuller description. The minor acid intrusions, acting as lines of weakness in the gabbro mass, suffered intense deformation which has been described in part already (Read, 1951). The present portion of this account can therefore be devoted mainly to a description of the altered hypersthene-gabbro



A Granulated pyroxene-granulite, Currach Pool, Clatt. Porphyroclasts of diopside in a granulated base of fine-grained diopside. Ordinary light; × 14

B Fractured and veined hypersthene-gabbro, Bin Hill, Leslie. Ordinary light; × 14

C, Fractured, mylonitised and silicified granite, Charleston, Leslie. Rounded porphyroclasts of quartz in a granulated and silicified base. Crossed nicols; × 14

and granitic-dioritic rocks in general, together with altered olivine-gabbros from the Ledikins and Rothney belts of disturbance which lie north of the contact shear-belt. A picture of the dislocation-metamorphism undergone by the rocks of the Insch intrusion as a whole will be obtained thereby.

(a) **Modifications of Hypersthene-gabbro.** Where they are least altered the hypersthene-gabbros consist of hypersthene, labradorite, augite and iron oxide, with small amounts of biotite. The texture is somewhat variable, the finer-grained types showing a granulitic texture and the coarser types a more irregular arrangement of their minerals. Over much of its outcrop, however, the gabbro is profoundly altered, both by a general amphibolitisation of the pyroxenes and by the development of threads and veinlets of secondary material crossing the rock (Plate 5, B). In general, the amphibolitisation, veining and cataclasis in the hypersthene-gabbro increase in intensity towards the south-western contact.

Over a great part of the main hypersthene-gabbro which forms the southern part of the Insch mass, the rocks are traversed by narrow green veins. Typical examples of early stages of this veining can be examined on the craggy ground of Ardoyne, one and a half miles east-south-east from Insch. Here a multitude of chloritic threads run often parallel to one another in each outcrop, but, though generally flattish in attitude, do not seem to possess a common direction. Similar green threads and veinlets are well developed in the crags around Overhall and Foreside and elsewhere, and appear to increase in number and thickness towards the south-western contact. Thus, on Bin Hill, Leslie, innumerable green veins reach a thickness of a quarter of an inch (Plate 5, B).

A second aspect of the modification of the hypersthene-gabbros is their transformation into fine-grained dense amphibolites; such rocks often vary in grain size, a circumstance giving rise to a marked banding developed, for example, on the craggy ground around Overhall and south to the Gadie Valley. Such banded rocks are well seen at the southern contact with the Bennachie Granite around Parkbrae. Here large glaciated surfaces rising southwards towards Bennachie provide excellent exposures of coarse speckled greenstone banded with fine-grained dense greenstone, the latter becoming dominant towards the contact. The impression is given of movement parallel to the contact resulting in the production of finer greenstones.

Along certain definite interior belts, and at many localities along the southern contact, the hypersthene-gabbro is sheared and mylonitised. What is most likely to be the eastward continuation of the Rothney shear-belt is seen in the bluffs of the Shevock and the Urie and in the nearby quarries in Pitmachie Wood—all some two and a half miles east of Insch. In this area, the hypersthene-gabbro is traversed by great numbers of shatter-belts and shear-planes coated with slickensides; some conspicuous planes are inclined at high angles to the north-east. Minor belts of dislocation are common around Overhall and Foreside where crushed gabbros are seen to pass into denser greenstones.

Details of the petrographical characters of the modified hypersthene-gabbro are now given. The veins traversing the gabbro consist of a variety of minerals. Many veins are made of chlorite, a few of chlorite and zoisite or of chlorite and calcite; veins of chlorite occasionally traverse the amphiboles of the amphibolitised gabbros. A large number of veins are composed of small blades of amphibole, either colourless or, more usually, greenish or bluish-green; occasionally, amphibole needles growing vertically from the vein-wall are bent sideways. The veins, whatever their composition, often run in parallel sets across the thin section. Near them, the cleavages or twin planes of the plagioclase may be slightly faulted. Where a chlorite vein traverses amphibole the latter is chloritised near the vein, and where amphibole veins traverse pyroxenes these are converted into amphibole similar to that of the veins. Adjacent to some amphibole veins, patches of amphibolite similar to that described immediately have been formed. This is particularly the case when the veins occur as a complex system. Occasionally the amphibole aggregates have their rims of a deeper greenish-blue colour. It is certain that some amphibolitisation is related to veining and thus, since the veins clearly occupy a fracture system, to a dislocation process.

The amphibolites proper often show but few evidences of dislocation. In these rocks, the pyroxenes are replaced by aggregates and mats of bladed or fibrous amphibole, pale greenish in colour and with deeper greenish-blue margins but brownish near iron-oxide grains; the felspars are often sericitised and saussuritised. In many rocks, the amphibole substance has moved from the original pyroxene position and the aggregates have coalesced in places to give a continuous nexus pricked through with rounded felspars. Amphibole blades spear from the edges of the aggregates into the felspars and much wandering of amphibole material from the edges of the aggregates is apparent in many rocks.

Cataclasis is developed to varying degrees in the modified gabbros—particularly in those along the southern contact. It is shown in the plagioclase by bending, breaking and faulting of original twinning, by the production of a very fine twinning, often in a chessboard pattern, that is presumably new, and by lensing and shearing in the advanced stages. Residual pyroxenes develop an emphasised parting or partings. In markedly affected rocks there are narrow bands of mortared or micro-brecciated material in which amphibolitisation has taken place. Curving shear-belts of such material are observed in some slices. In the most advanced stages the modified gabbros have the textures of mylonite, the rocks being made up of bands, lenses and wisps of amphibolitic substance of varying grain size and nature, separated by shear-planes in some cases. Read (1951) has described the micro-brecciated and amphibolitised gabbros at the contacts of the mylonitised porphyrite dykes at the Kennels of Westhall, Oyne. Mention may be made of the completely silicified rock (possibly a silicified and brecciated gabbro) that crops out at Drumtootie, north-east of the Kennels (see Read, 1951, fig. 1); with this possible exception and another from Meiklenewton Hill, Clatt, good silicification has not been observed in the hypersthene-gabbro.

It is evident from these descriptions and from Read's earlier work (1951) that some amphibolitisation is associated with dislocation processes. It remains to discuss how much is to be ascribed to this process, since Read (1935) for the Haddo House Mass, Whittle (1936) for the Insch Mass and Stewart (1946) for the Belhelvie Mass, have considered that very similar rocks have been produced by end-stage modification of primary igneous minerals during the final stages of magmatic consolidation. It must be admitted that the completely amphibolitised gabbros are rarely veined, whilst the much veined gabbros are only slightly amphibolitised. The veins occupy fracture systems and there are undoubted evidences of cataclasis culminating in mylonitisation in the gabbros, so that a dislocation-metamorphism has certainly affected the Insch gabbros. Whilst some small part (not yet capable of delimitation) of the Insch amphibolitisation might be referable to end-stage processes, the writer prefers to consider that the major part is the result of dislocation-metamorphism. The observed increase in amphibolitisation towards the south-western contact coincides with an increase in mechanical deformation of the associated rocks. The absence of discrete veining in many of the Insch amphibolites may possibly be a matter of scale: the channels of approach along which the fluids came which effected the metasomatism of the pyroxenes may well have been innumerable, sub-microscopic fractures. The veined rocks may represent the utilisation of a few large fractures, the amphibolites the utilisation of a multitude of tiny fractures, the total amount of material involved in the two cases at any one stage or place being roughly equivalent.

(b) **Modifications of the Dioritic, Granitic and Pegmatitic Rocks.** Rocks of the **dioritic group** (Sadashivaiah, 1954a) occurring at the western edge of the Insch mass rarely show deformation-effects. In some of these rocks the biotite is chloritised and the primary amphibole partly replaced by a paler bladed variety—but these changes may not be due to dislocation. At certain localities in the southern portion of its outcrop, however, the diorite does show excellent cataclastic phenomena. As already noted, in rocks occurring south-east of Druminnor House, and in Windseye Wood at the southern contact west of Hillside, mylonitic bands are well developed, the quartz shows undulose extinction and shearing is apparent.

In the north-western part of the Insch mass, around Kennethmont, the **granite-syenite** (Sadashivaiah, 1954a) presents modifications of considerable interest which may be described here, as they are apparently related to the dislocation phenomena seen along the southern contact. At many places the rocks are traversed by numerous narrow parallel veins of quartz or of quartz and chlorite. Over much of their area the rocks show various degrees of silicification. In the early stages of this process the rock is broken up by veinlets of bladed quartz, often with a comby texture. In more advanced stages, much of the rock is replaced by fine 'felsitic' quartz in criss-crossing blades, often traversed by veins of much coarser comby quartz; angular relics of the original minerals remain in the 'felsitic' base. In the final stage few relics persist, the resulting rock being mainly a mass of secondary quartz, often with druses and cavities lined with minute crystals. Early stages in this silicification are seen around Coldhome and Candle Hill, near the Home Farm of Leith Hall (for these localities see fig. 1, Sadashivaiah, 1954a) and elsewhere, whilst the completed result is provided by the remarkable rocks of Cunrie Craig (Fig. 1), immediately west of Candle Hill. The summit of Cunrie Craig is made of silicified rock, the base of olivine-gabbro. Some of the Cunrie Craig rocks closely resemble rocks included by Mackie (1914) in his Craig Beg Series of Rhynie, a series containing the famous Rhynie Chert. In general the characters of the silicified rocks agree with those resulting from fracturing of a solid rock followed by a silicification of non-hydrothermal type. The process can reasonably be attached to the other phenomena of dislocation already described from the Insch mass.

The granitic rocks along the southern contact south-west and south-east of Clatt are not well exposed but such outcrops as are available reveal beautiful granitic mylonites showing porphyroclasts of felspar in a granulated quartzo-felspathic base streaked with biotitic trails and smears; such a rock comes from just east of Smallburn where it must be practically on the contact. As already mentioned, immediately north of Charleston, in the south-western contact shear-belt, silicified, brecciated and mylonitised granitic rocks are seen (Plate 5, C). This association of cataclasis and silicification lends support to the proposal already made that the widespread silicification of the Kennethmont granite-syenite is an expression of dislocation.

The **small granitic and pegmatitic bodies** intruded into the main gabbros all show advanced cataclasis. Mylonitisation in such bodies east of Oyne has been described in detail by Read (1951). Other examples of deformed pegmatites occur in the Rothney and Ledikins shear-belts and at numerous other localities. The acidic rocks are crushed, brecciated and mylonitised, even when they are invasive into gabbros that show no signs of cataclasis. Deformation in the pegmatites is registered by the bending and faulting of felspar twin-lamellae, by the cracking, straining and granulation of the quartz and by the development of innumerable planes of liquid inclusions in this latter mineral. Beautiful ribbon-mylonites have been developed in a granitic dyke traversing the hornfelses near the gabbro contact at Knockollochie, Pitcaple, east of Bennachie (Read, 1951). Once again mention may be made of the mylonitised porphyrite cutting the gabbro at Kennels of Westhall, Oyne, and of the brecciated and amphibolitised gabbro at its margin. It is clear that these acidic dykes formed weak places in the gabbro during the dislocation episode.

(c) **Modifications of the Olivine-gabbro.** Olivine-gabbros and their more acid derivatives occupy much of the northern part of the Insch mass. They show less widespread secondary modifications than the hypersthene-gabbro which lies nearer to the zone of disturbance along the southern contact, although sporadic examples of fracturing and microveining can be found. These modifications increase towards the south of the olivine-gabbro outcrop and become especially conspicuous near the Ledikins and Rothney belts of shearing.

In the modified olivine-gabbros the stages of increasing mechanical disruption are those marked by simple fracturing, by fracturing and microveining, and by fracturing, microveining and the opening up of mineral cleavages. Two stages of chemical alteration can be distinguished: transformation of minerals and silicification. On occasions these two classes of change appear to be independent of one another, but in general it can be said that mineral changes accompany disruption. Apart from the modifications here described, the olivine-gabbro is a singularly fresh rock.

In the stage of simple fracturing, the rocks are traversed by knife-edge fractures, usually not parallel, running through all the minerals. In the next stage, where veining accompanies the fracturing, the rocks are crossed by thread-like dark veinlets which often have slickensided walls. In thin slices the veins are seen to be located in minute shatter-zones, 0.5 mm. wide, in which run several filamentous chloritic veinlets. Sometimes all the veinlets are parallel, but more often they cut the rock into angular compartments. There is no movement apparent on the veins. The vein material is chloritic and passes through all the mineral constituents, including iron oxide, without change. In the third stage, fracturing and veining are associated with penetration along mineral cleavages; the veins are thicker and more numerous and the rock assumes a dulled appearance; micro-brecciation may take place along the shatter-belts. In the rest of the rock, the cleavage-planes of the felspars are opened up and filled by threads of chlorite which do not cut across the grain-boundaries. In this stage, the vein-filling varies —usually it is chlorite, often there is a central portion of calcite, and occasionally the vein is made of a blue-green amphibole.

The mineral alterations associated with the fracturing cause the rocks affected to look dull and rotted. The following transformations are observed: the olivine passes into serpentine and iron oxide, the latter in some examples completely replacing the original olivine; the pyroxene undergoes a variety of changes, giving chlorite and iron oxide, or a mixture of calcite chlorite and probably sericite, or a yellowish or blue-green amphibole; the biotite is transformed into a non-pleochroic, possibly non-crystalline, brown material; the plagioclase is sericitised or partly chloritised by the widening of chlorite threads along the cleavages. The final stage of mineral alteration is marked by silicification which proceeds progressively along cracks, in pools and round-ended projections, and leaves isolated rock-relics in which the original minerals are always completely transformed. Iron-oxide dust provides the last trace of the original constituents.

4. CONCLUSIONS

The modifications of the major rock-types of the Insch intrusion due to dislocation-metamorphism have now been detailed. A selective reaction to stress is controlled by rock-type and geological setting. Whilst there may be a number of phases in the dislocation-metamorphism, it is evident that one major episode is concerned, of a date later than the intrusion of the late granitic and pegmatitic dykes. Apart from localised belts of intense dislocation, it is clear that the intensity of this late dislocation increases towards the southern contact of the mass and especially towards the western portion of this contact.

The significance of this fact is enhanced by the contrast in character between the south-western contact and those of the remaining portions of the Insch mass. In the broad aureole along the northern side of the mass, neither the contact rocks nor the granite veins penetrating them show important signs of deformation. There is abundant evidence that the contact is a natural one. Nothing of the actual contact can be seen at the east end of the mass, but Sadashivaiah (1954) has advanced geometrical reasons for suggesting that roof rocks occur both on the northern and southern sides of the mass. East of the Bennachie Granite, the country-rocks along the southern contact are again seen to be hornfelses, although they are sheared locally and granitic dykes in them are mylonitised (Read, 1951).

The characters of the contact west of the Bennachie Granite have been described in detail. Here there is no normal aureole of thermal metamorphism. The pelitic rocks of the contact zone are strongly sheared, the vertical shear-planes running parallel to the contact. Highly deformed diopside-granulites, types rare in the normal country-rocks, appear to be concentrated along the contact zone. There is, moreover, a mixing of all rock types on a scale ranging from that of the serpentine lenses which reach two miles in length to that of the sheared melanges seen in some of the quarries. In these melanges, each lenticular component stands steeply with its strike parallel to that of the contact.

On the basis of these observations, it is clear that this portion of the Insch contact is formed by a belt of dislocation. The rocks south of the contact have moved relatively upwards, so that any southward continuation of the igneous rocks and their thermal aureole has been removed. This upward movement has produced the shears in the gabbros on the northern flank of the moved block. It has given rise to the close-set vertical structures in the movement zone and has permitted the uprise of tectonic pods of serpentine along it. In the movement zone, tectonic mixing of the rocks has taken place; the exotic unctuous serpentines are accompanied by slices of local rocks and by a concentration of calc-silicate rocks—these latter presumably being mobilised and collected from a lower level. The contact of the Insch mass in this sector is completely mechanical.

If the suggestions are correct concerning the nature of the contacts, as advanced here and by Sadashivaiah (1954), it seems probable that the exposed Insch gabbros form the culmination of a flat dome, disappearing northward, eastward and south-eastward beneath an unmoved roof, but cut off in the south-western portion by a powerful vertical dislocation. Nowhere is the floor of the intrusion exposed.

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DISCUSSION

DR. MAURICE WELLS said that he had greatly enjoyed hearing Professor Read's very interesting account of the Insch intrusion Complex. In his description of the eastern end of the Complex, Professor Read had referred to roof-structures, adjacent to the banded troctolites and peridotites, which were the most olivine-rich members of the 'Differentiation Series'. As the normal arrangement was for such rocks to occur near the floor of a layered intrusion, if accumulated *in situ*, it would be interesting to know the reason for inferring proximity to a roof in the present instance.

The speaker concurred with Professor Read in believing that many hypersthene-rich gabbros are products of reaction between ordinary gabbro magma and assimilated pelitic rocks. The Tertiary Hypersthene–Gabbro intrusion in Ardnamurchan provided a case in point. This is abnormally hypersthenic, and of all the Ardnamurchan intrusions it makes the most extensive contact with pelitic rocks; yet xenoliths of recognisable pelitic origin are scarce, though those derived from other sources, notably basalts, are abundant. The inference was that pelitic rocks had been more completely digested.

Professor Read had likened the banding in the gabbros to sedimentary structures and had suggested that when the banding was very steeply inclined, as in the Huntly mass, this might be due to original slumping rather than to secondary tectonic causes. The present speaker's experience of banding in the gabbros was that it was generally strikingly regular and that evidence of slumping was exceptional. Could Professor Read give any positive evidence that slumping had operated in the Huntly intrusion?

PROFESSOR READ, in replying, stated that Dr. Wells had broadened the discussion to range over not only the Insch mass but also the Newer Gabbro Province of north-east Scotland. Accepting this extension, Prof. Read considered the eastern part of the Insch mass, as exposed, was thinning towards the east and the exposed roof and the concealed floor were coming together. He was gratified to have Dr. Wells's support for a contaminated origin of the hypersthene-gabbro; he had always considered the Ardnamurchan hypersthene-gabbro to be of that origin. The question of the attitude of the banding in the gabbros of north-east Scotland was a difficult one; there appeared to be two main alternatives—either the originally flat banding had been inverted by post-gabbro regional movements, or some sort of pre-consolidation disturbance, such as slumping, had taken place. Prof. Read considered that post-gabbro inversion was a solution difficult to accept, but admitted that direct evidence for slumping in the Huntly gabbros had not yet been produced. Clearly, further investigation of this important question was required.

On the Occurrence of Micaceous Haematite in the Hennock–Lustleigh Area, Eastern Dartmoor

by F. A. HENSON *

Received 24 July 1954; read 4 May 1956

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ABSTRACT: In the Hennock–Lustleigh area, east Dartmoor, extremely fine-grained micaceous haematite occurs sporadically in a number of lodes of east-north-east trend. During the summer of 1951 a search for new lodes of this composition was made by members of the Department of Geology, University of Nottingham, using both electric and magnetic geophysical methods. This paper summarises the results so obtained.

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1. INTRODUCTION

FOR WELL OVER a century specular haematite has been mined in the central and north-eastern parts of the Dartmoor granite. At Birch Tor, in the centre of Dartmoor, several tin mines were worked at one time where specular haematite occurs in intimate association with cassiterite. According to MacAlister (1909) the amount of specular haematite in the lodes of this area may be as much as 20 per cent. Unfortunately this ferruginous by-product of the tin mines (specular iron-ore containing 58.2 per cent of iron) proved useless, commercially, since it is too hard to grind to a pigment and not suitable for smelting. In the Hennock and Lustleigh areas the specularite is of much finer grain and has been mined extensively for use in the paint and other industries. Generally it is known as micaceous haematite, or micaceous iron oxide. This paper deals with the occurrence of

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* It is much regretted that Dr. F. A. Henson died suddenly on Sunday, 13 January 1957, while this paper was passing through the press. Ed.

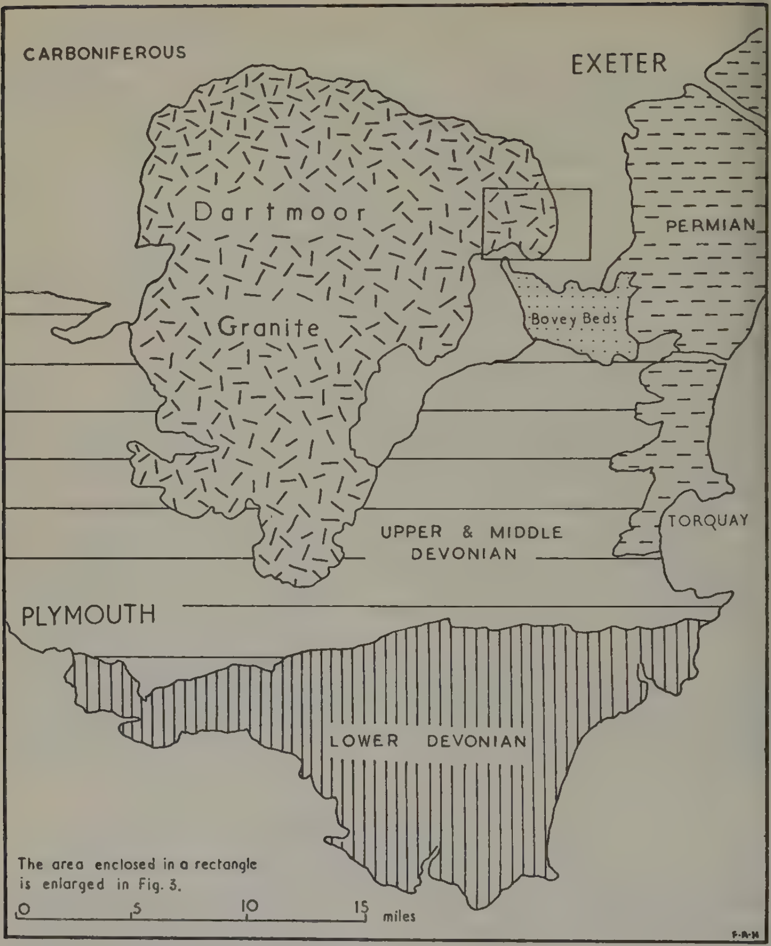


Fig. 1. Geological map of South Devon showing area in which micaceous haematite lodes occur

micaceous haematite in this north-eastern area of Dartmoor and particularly with the results of geophysical prospecting for new ore bodies of this composition in the Hennock area.

The earliest reference to micaceous haematite, or the shining ore of Dartmoor, was by De la Beche, in his Report on the Geology of Cornwall, Devon and West Somerset, published in 1839. It was then sold as a writing sand at prices ranging from three to eight guineas a ton. During the middle part of last century lead, silver and zinc were mined in the Christow–Hennock–Lustleigh area, but very little micaceous haematite was raised. However, a little brown haematite (limonite) was produced from some of the mines in the area. Towards the end of the century micaceous haematite was found to be very suitable as a pigment for paints—especially for anti-corrosive paints. As a result, production of the ore increased considerably. By the close of the century, several thousand tons of ore had been raised from the Hawksmoor, Kelly, Plumley, Shaptor and Shuttamoor mines. Production from these mines dwindled at the beginning of the present century, with the exception of the Kelly Mine which continued to produce until 1952. At various times—particularly during the period 1940–6—many of the old dumps at these former mines were re-worked by modern extraction processes and during these years the total production of micaceous haematite probably exceeded 1000 tons per annum from all sources.

The Great Rock Mine at Hennock first produced ore in 1902. Since that time the output of micaceous haematite has probably varied between two and six hundred tons per year. The development of this small but efficient mining enterprise has followed the increasing demand for its product by the paint and other industries. The micaceous ore of the area is extremely fine-grained—much finer than that of the Lustleigh or Birch Tor areas. When handled in the raw state it leaves an almost oily smear on the fingers. After washing and drying, the top grade product will pass through a 200-mesh sieve with only 1 per cent of residue.

In the past the ore was washed, to remove granitic material, and the residue stamped and washed again with the wash-water. More recently, the method of obtaining good and uniformly-treated ores has been to crush the vein rock and remove the greater part of the impurities of granitic material and pyrites by centrifuging. After leaving the centrifuge, the concentrate was dried by a continuous process and finally passed through magnetic separators. The method now employed at Great Rock Mine is, firstly, to wash the ores with water jets, the wash-water carrying the extremely fine material to vibrating rifled tables. The ore is also hand picked in the wash-down and coarse material removed. On the tables the pyrites, quartz, feldspar and other gangue is removed whilst the concentrate is water-borne to settling tanks and drying sheds. The use of settling tanks enables several grades of the product to be marketed after drying at red heat to roast off the sulphur which may still be present in minute amounts of pyrite. With a mineral product which passes a 200-mesh sieve great care has to be taken at all stages to eliminate loss both in air and water.

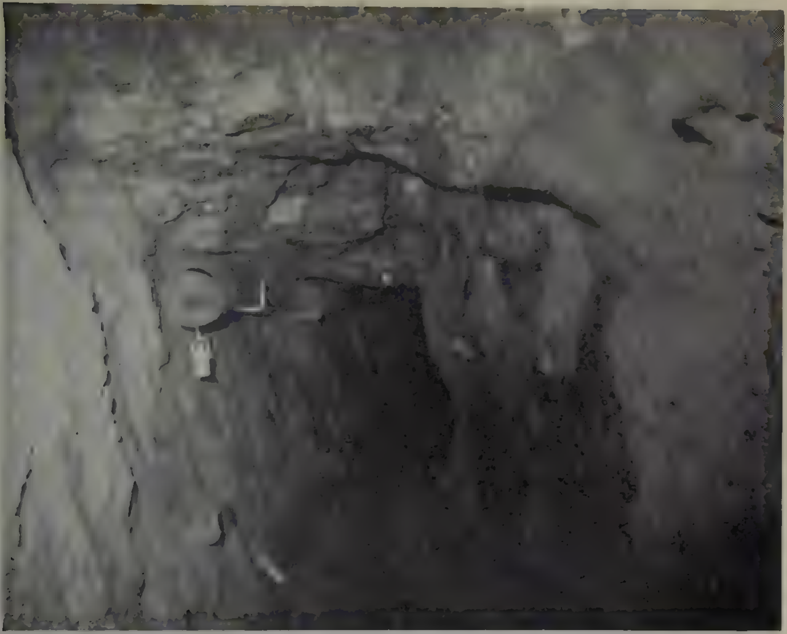
2. FIELD OCCURRENCE

The general bearing of the micaceous haematite lodes in the Birch Tor, Lustleigh and Hennock areas is east-north-east. With the exception of one lode (in the Great Rock Mine at Hennock), all known lodes are confined to the granite mass. The lodes in the central part of Dartmoor have been described by MacAlister as more or less vertical fissures filled with gangue or veinstones showing no signs of brecciation (1909, p. 405). The granite of this central area is mainly a coarse porphyritic type with numerous fine-grained granite intrusions. In many cases the granite in the immediate vicinity of the lodes is a rotten kaolinised rock.

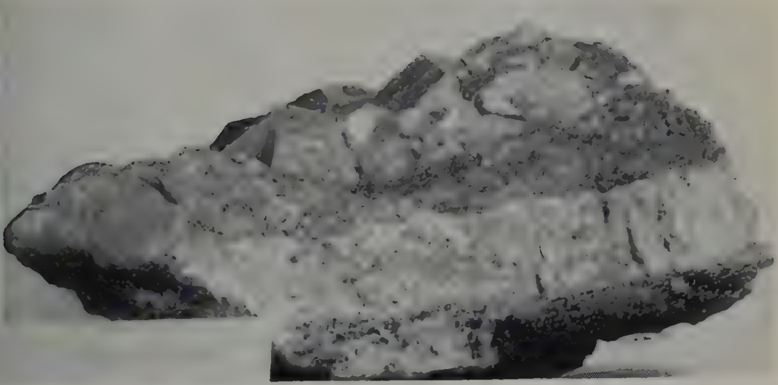
In the Kelly and Hawksmoor mines the lodes vary from an inch to over two feet in thickness in a coarsely porphyritic granite very similar to that of the Birch Tor area. Again, the granite in the neighbourhood of the lodes is often kaolinised. This altered and rotten granite frequently contains abundant, coarse flakes of ore. In the Shaptor area a fine-grained younger granite occurs. There seems to be no relationship between the occurrence of this rock and the distribution of the lodes. Now that the Kelly Mine is closed, there are no mines operating in the area west of Shaptor Rock. The specimens of ore and country rock from the Hawksmoor, Plumley and Shaptor mines have been obtained from the old workings, and the lodes mapped from the evidence which remains of open cuts and pits.

At the Great Rock Mine, where mining and exploration for reserves is actively proceeding, it is possible to obtain a clearer understanding of the occurrence of the lodes in eastern Dartmoor. Prior to carrying out the geophysical prospecting on the mining property all the lodes and underground workings were examined. The main lodes and workings of the mine, and the prospecting traverses, are represented on the map showing the distribution of known lodes and mines in this area (Fig. 3). At Hennock the main lode has been worked from near the granite-sediment contact in a westerly direction for over six hundred yards. The development has been through a number of adits, stoped to the surface at several points and winzed to a depth of below 350 ft. O.D. It is now exhausted. In addition to this lode there are others, including one running out into the Culm, which have been worked from the east. There are also two major north–south cross-cuts. From Beedon Lane, adits have been driven into the eastern side of the hill under which the workings have been driven from the east; some yielded good ore in quantity, while others have failed.

In the Hennock area the lodes strike east-north-east and nearly all dip steeply to the north. Underground the lodes are found to be slightly irregular in direction and are frequently displaced by minor north–south faults with throws of from a few inches to a few feet. In most of the workings the hanging and foot walls are discernible. Slickensided surfaces are common, particularly on the foot walls, and suggest some vertical movement in the granite prior to mineralisation. In the most eastern development of the lodes (in Culm) there is considerable brecciation of the country rock. The granite at Hennock is a coarse porphyritic type with considerable



Worked lode in Great Rock Mine, Hennock, South Devon, showing foot and hanging walls



Part of micaceous haematite lode from Great Rock Mine, Hennock, South Devon. The specimen shows a central band of kaolinised and mineralised granite above which are massive iron pyrites and some haematite. The lower part of the specimen shows typical development of micaceous haematite

variations in texture. Near to the contact there are xenoliths of hornfelsed sediments contaminating the granite. Small aplitic veins and masses of aplogranite also occur. In the neighbourhood of some of the lodes, especially in the northern part of the Beedon Lane workings, the granite is considerably kaolinised.

The distribution of ore bodies in the lodes is very sporadic, a factor which adds to the cost of mining in the area. In places the width of the mineralised zone is only a few inches with only a faint smear of ore, while a few feet farther on an ore body four feet in width, and many feet in vertical and lateral extent, may occur. Such ore bodies are worked both by overhand and underhand stoping.

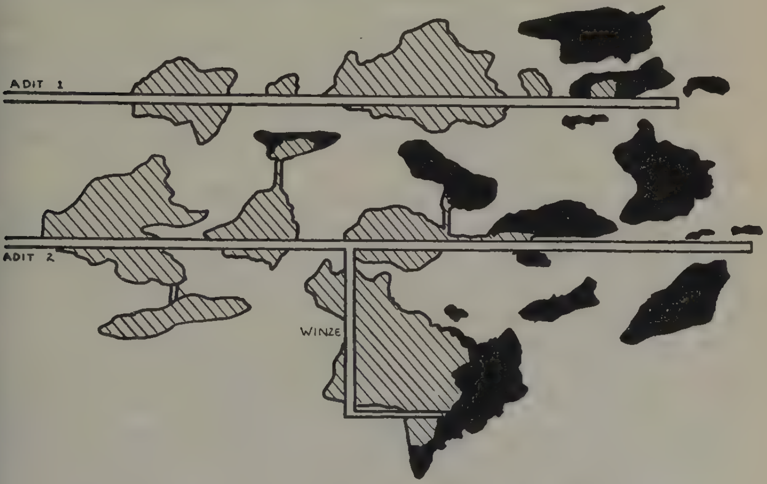


Fig. 2. Diagrammatic section showing the distribution of unworked (black) and exhausted (cross-hatched) ore bodies of the Main Lode, Great Rock Mine

Such an irregular distribution of ore calls for exploratory drilling in all possible directions. Frequently new ore bodies are revealed by staining of the rock wall and when water is present, by slow flowages of water-lubricated ore. In some parts of the lodes, particularly where there is a considerable amount of kaolinised and mineralised granite, iron pyrites occurs in perfect pyritohedra. This latter is of earlier formation than the micaceous haematite.

3. PETROGRAPHY

(a) **Granite.** Macroscopically, the granite in the Hennock–Lustleigh area is predominantly a coarsely porphyritic rock similar to the 'Giant Granite' described by Brammall & Harwood from the nearby Haytor area. The constituent minerals are abundant quartz, phenocrysts of orthoclase up to three inches in length, plagioclase feldspar, shining plates of biotite and sporadic irregular patches of dark blue tourmaline. Occasionally this granite exhibits rapakivi structures, with pale yellowish-brown plagioclase feldspars rimming the potash feldspar phenocrysts. Mineralogically the granite shows little variation within the present area, but its texture, and the sizes of the constituent minerals, is distinctly variable. The colour of the granite varies from a mottled grey or light reddish-brown to a darker red in the neighbourhood of the iron-bearing lodes. This colour is controlled primarily by the amount of weathering and by the degree of kaolinisation. Quite distinct from the porphyritic granite are younger aplogranites of the Hennock and Shaptor areas. These rocks are similar to those described by Brammall & Harwood as being below the 'Giant Granite' at Haytor. They are very fine-grained and of a mottled pale cream and reddish-brown colour. They differ from the older granite, not only in texture, but also in their mineralogy. They contain slightly more tourmaline and less biotite than the older porphyritic granite.

Microscopically the porphyritic granite clearly resembles the description of the 'Giant Granite' given by Brammall & Harwood. Detailed accounts of the petrography of this and other Dartmoor granites (including the aplogranites) have been given by Worth, Flett & Dewey, in addition to the four main papers by Brammall & Harwood.

(b) **Ore-bearing Granite.** Macroscopically, the ore-bearing granite is variable in colour depending upon the degree of kaolinisation of the feldspars, the presence of thin or thick veins of micaceous haematite and the occurrence of iron and copper pyrites. In the neighbourhood of the Kelly and Hawksmoor mines this granite is characterised by its attractive mottled blue-grey and pale yellow colour. The mottling is due to abundant clusters of coarse flakes of specularite in an almost completely kaolinised rock. The sizes of the individual flakes vary between 0.05 and 0.40 in. in diameter. Locally this rock possesses a distinctly purple colour, whilst in some of the lodes a deep reddish-purple clay also occurs.

Farther to the east, in the Great Rock area, the ore-bearing granite is only partially kaolinised. Here it is a dull grey-blue rock in which the fine micaceous haematite is either disseminated, or occurs in minute veins. Iron pyrites is frequently present in the ore-bearing granite, usually appearing as minute crystals within the granitic gangue and occasionally as larger crystals on the outer margins of the ore-veins. Usually it is earlier that the micaceous haematite. In one lode an unusually large cavity revealed pyritohedra more than two inches across. The amount of pyrites in these ores is very small, however.

Microscopically, the ore-bearing granite differs from the granites pre-

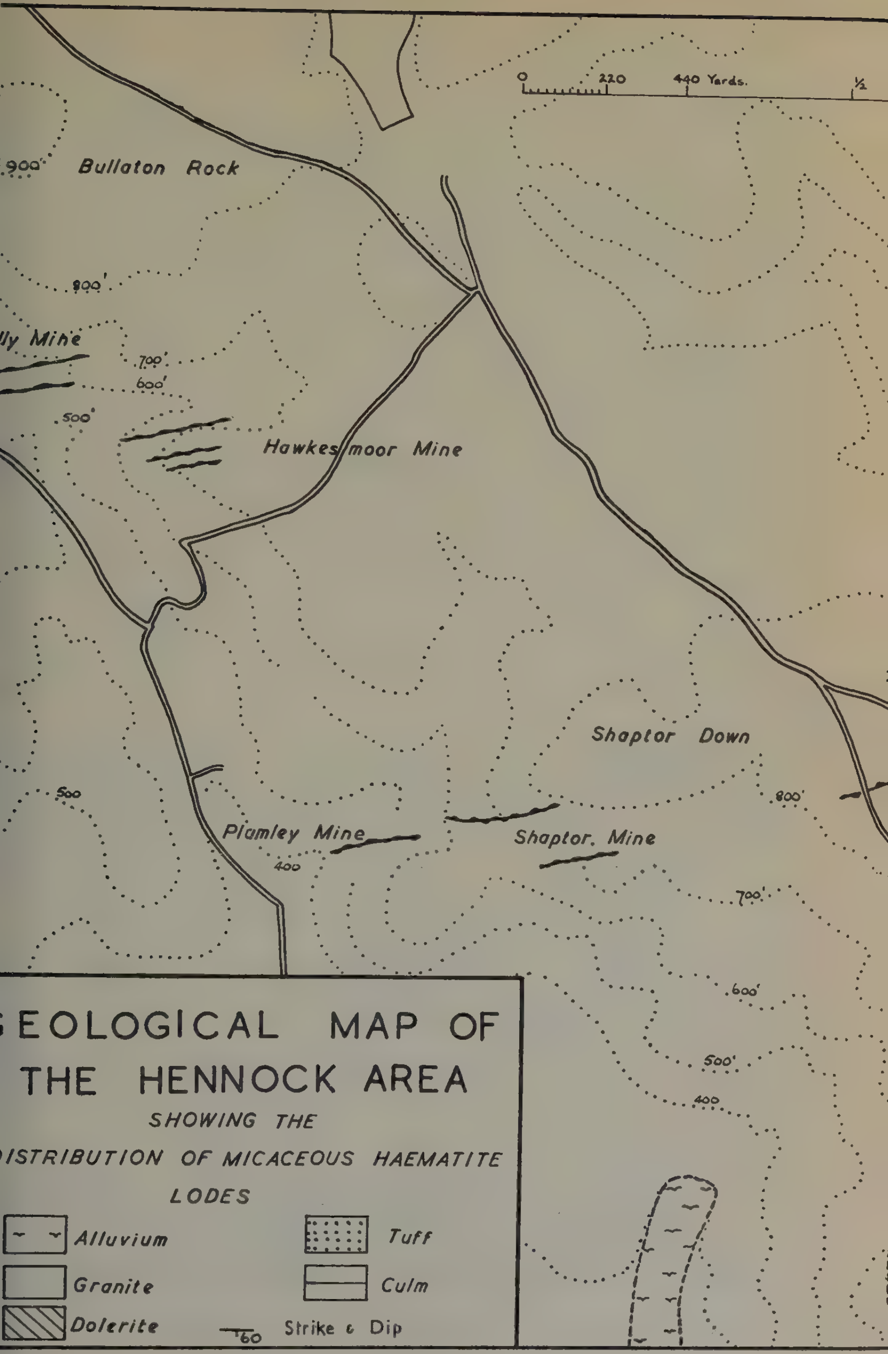


Fig. 3. Geological map of the Hennock area, East Dartmoor, showing t

viously described in that it is considerably brecciated and has its feldspars completely kaolinised. All the larger quartz crystals have suffered considerable mechanical deformation. Undulose extinction is very common, while many crystals show clear-cut fracture zones and mortar structures. Some of the fracture zones contain abundant but minute flakes of micaceous haematite. Tourmaline is a common inclusion in quartz. No fresh feldspars are present, since alteration to kaolinite, sericite and some quartz is complete. Invariably the biotite is partially altered to chlorite and muscovite, and when present, is usually associated with ilmenite and haematite. Tourmaline is both sporadic in distribution and variable in habit. Commonly it is present as blue acicular radiating groups of crystals. Sometimes t is associated with biotite, frequently with quartz and occasionally with ltered feldspar. Both at Shaptor and at Hennock euhedral zoned tourmaines occur in ore-bearing granite. These zoned tourmalines (Fig. 4) are very similar to those described by Brammall & Harwood. The tourmalines examined are also parti-coloured and appear to be later than most of the haematite. Very occasionally minute tourmaline crystals occur as distinct zones in secondary quartz. Also associated with tourmaline is cassiterite in mall amounts. Apatite, cordierite, garnet and zircon occur also.

Haematite is found in comparatively well-defined zones and as scattered nclusions within the altered feldspars and quartz. Also it occurs at the

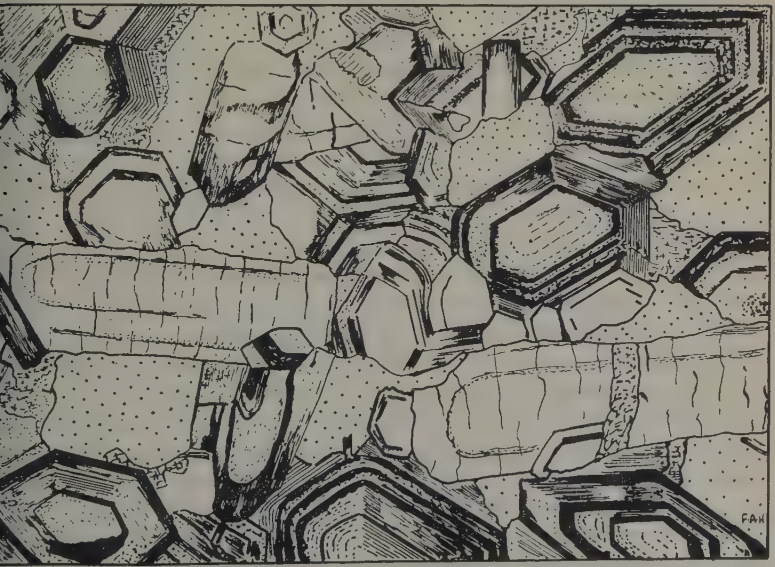


Fig. 4. Zoned tourmaline in granite from the Shap Tor Mine. Ordinary light; × 60

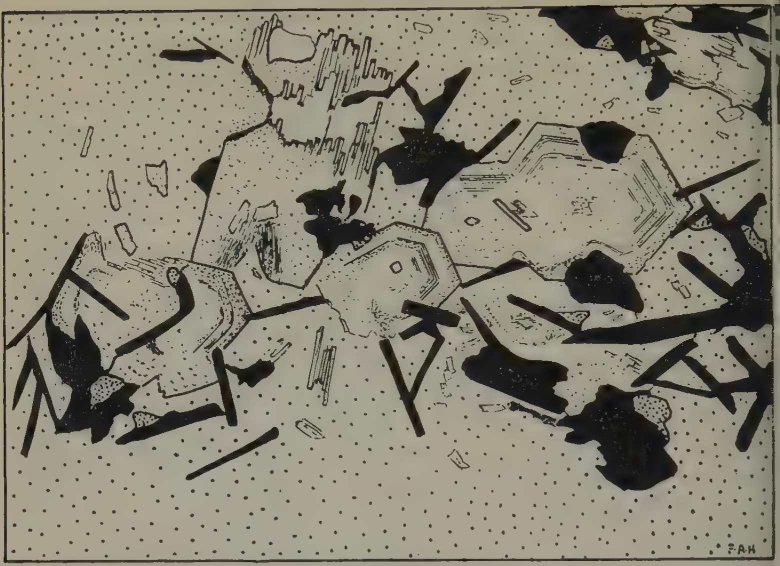


Fig. 5. Micaceous haematite veinlet in kaolinised granite. Black crystals are haematite, the stippled margins of which represent translucent haematite. Also present are zoned tourmalines. Ordinary light; × 50

margins of these minerals in irregular clusters. The general appearance of the ore-bearing granite under the microscope is shown in Fig. 5. Generally the ore is opaque, but the margins of many crystals are a deep transparent red.

(c) **Micaceous Haematite Ore.** Macroscopically, the ore is variable in colour and appearance. Near Lustleigh it is massive and fairly hard, while in the Hennock area it is soft and unctuous, even when mined. The ore from the western area is a dark steel-grey colour and that from the Hennock area is slightly lighter in colour. Sometimes it has a faint purple tinge. Its specific gravity varies between 5.10 and 5.15. It is non-magnetic.

Microscopically, the ore is predominantly opaque in transmitted light and a blue-black colour in reflected light. However, some of the haematite transmits light and appears as deep blood-red crystals bordering the opaque ore, or as individual fragments and splinters within sericite and quartz. Some of the blood-red splinters show lamellar twinning and only partial extinction between crossed nicols. At high magnification no radial structure is apparent, but extinction is still irregular. This is attributed to the strong dispersion and the high refractive index of the mineral (2.94–3.22), causing internal reflection which disguises the normal extinction positions. Also associated with the ore are cryptocrystalline sericite, some quartz, tourmaline and occasional cassiterite.

4. RESULTS OF GEOPHYSICAL PROSPECTING

(a) **Variometer Survey.** Most of the micaceous haematite lodes in the Hennock area vary from an inch or less in width to an infrequent maximum of four feet and consist predominantly of non-magnetic ore with accessory iron pyrites. The main method of survey over the lodes was to measure the vertical component of the resultant magnetic field due to the earth and to any local rock body, at five-foot intervals in traverses across the known orientation of the lodes. By such means it was hoped that differences in magnetic field strength, from place to place, due to the presence of non-magnetic haematite ore bodies in the granite (containing magnetite) would give some indication of the forms and sizes of new lodes. To eliminate error due to diurnal variation in the intensity of the earth's magnetic field a variometer (kindly loaned by the Department of Geology, University College, Cardiff) was read at a base station to correct the values of the vertical component of the field, obtained by a portable variometer.

As an essential preliminary it was necessary to consider the most suitable positions for two major north–south traverses in the area. Account had to be taken of topography, crops, distribution of implement sheds, equipment and compressed-air lines to mines. Furthermore, since it was proposed to carry out electrical resistivity measurements along the same major traverses, it was also essential to have room to manœuvre this equipment beyond the limits of the magnetic traverses. During magnetic traverses, all iron and steel objects, both personal and agricultural, were removed to a distance of seventy-five yards from the variometer. The two major traverses (Nos. 3, 4) of 1950 ft. and 2150 ft. respectively, presented no serious difficulties, but in traverses Nos. 1 and 2 it was necessary to clear the line of traverse through gorse and scrub.

In Fig. 6 is shown part of traverse No. 4 between stations 1055 ft. and 1875 ft., obtained by a team of four observers working under ideal conditions. Three members of the team operated the traversing variometer (including the setting out of station-intervals of five feet between pegs separated by 100 ft.) and one on the variometer at the station base. To reduce both fatigue and boredom, all members changed their tasks every hour. This also enabled each man to have one hour in every four of comparative ease, reading the base variometer at ten-minute intervals. In addition to the geological implication discussed below, this traverse provides interesting information about the speed of working of the party, and its relationship to meal times.

In the upper part of Fig. 6 values for the intensity of the earth's magnetic field at the base station are shown in the form of a solid line. The dots represent uncorrected values obtained by the traversing variometer and are plotted against time. Each value is the mean of eight readings at any one station. Both major and minor variations are revealed by the base variometer, the former occurring over intervals of thirty minutes whilst over the whole period of observations the diurnal variation was nearly 100 gamma. The gradual increase in values obtained by the base variometer between 1400 hrs. and 1800 hrs. G.M.T.+1 is clearly reflected in the sympathetic rise in corresponding values yielded by the traversing variometer over the same period of time. The lower part of the diagram shows the topographic profile, with a fall from 780 ft. to 680 ft. and the corrected values of the earth's magnetic field at stations from 1055 ft. to 1875 ft. Here the values given by the traversing variometer are shown as a continuous black line. This shows only slight resemblance to the values plotted against time in the upper part of the diagram, thereby establishing the fact that for detailed traversing with small variations in the vertical magnetic force the use of a base variometer is imperative.

The corrected curve shows one major downward inflexion between 1360 ft. and 1380 ft., and secondary downward inflexions at 1500 ft. and 1560 ft. respectively. Between the major inflexions and the first of the two secondary inflexions indicated above there is a steep rise and then a gentle fall in the curve. The major downward inflexion on this traverse coincides exactly with the known position of a major lode, two hundred feet to the west. This lode produced a similar downward inflexion in traverse No. 3 and it is inferred that the major inflexion revealed by the traversing variometer in traverse No. 4 is either an ore body which is an extension of the main lode from Beedon Lane, or is a water-bearing fault zone. In Fig. 8, which shows the variations obtained in all the traverses, many such downward inflexions occur. Those which coincide with known lodes, or old workings which would produce the same negative anomaly, are indicated by slightly sloping solid lines. Where similar downward inflexions occur, but do not fall on known lodes, then two parallel dotted lines indicate a probable new ore-bearing lode.

(b) **Resistivity Survey.** Since the electrical resistivity of a rock is dependent upon its composition, its degree of compactness, its porosity and its water content it was thought at first that the use of a resistivity survey in the Hennock area would not be particularly fruitful. The reasons for this outlook were the faulted nature of the ground, the variations in the water-table (revealed by mine workings) and the irregular distribution of the ore bodies.

Prior to the resistivity survey at Hennock, preliminary trials were carried out in the grounds of the University of Nottingham, using an Evershed & Vignoles 'Megger' earth tester. As a result, suitable electrodes, percussion cap fittings over the electrodes, extractors and cable drums were made in

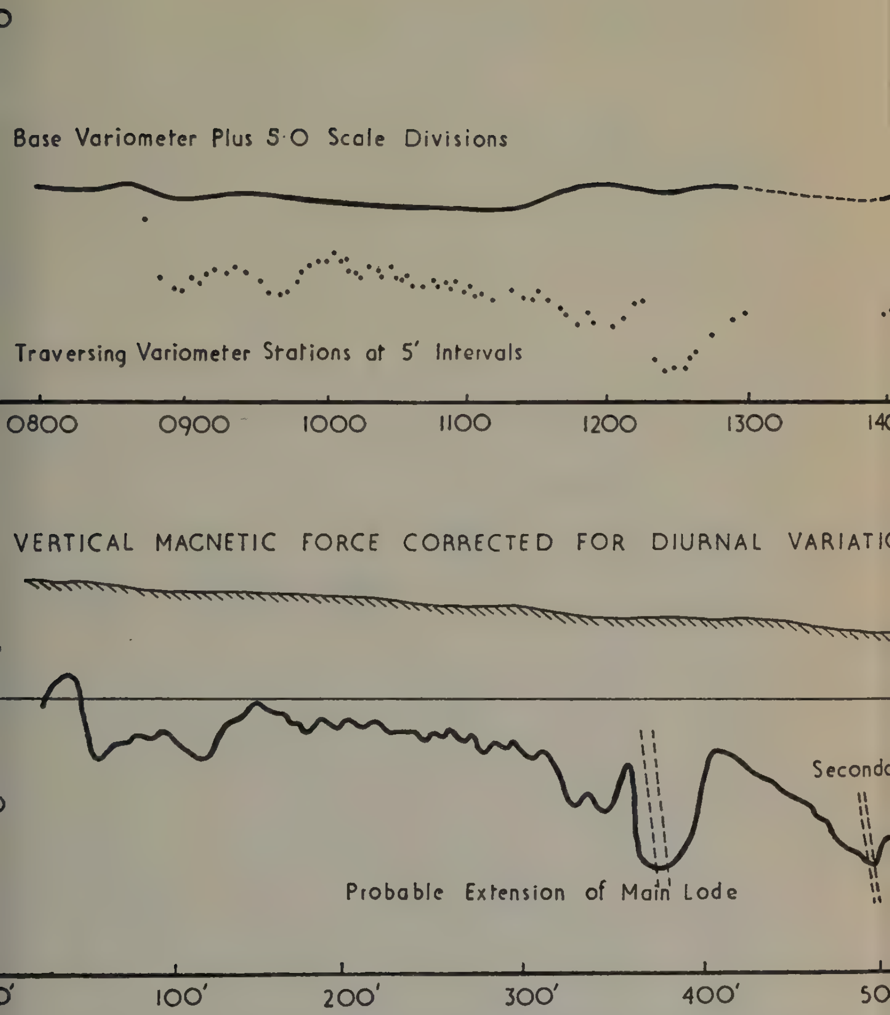


Fig. 6. Uncorrected and corrected readings of traversing variometer or

he workshop of the Department of Geology. Also tests were made with lectrodes buried to different depths, since it was expected that the variable hickness of soil over the granite might introduce appreciable errors. Iowever, as the result of a test in which the height of the water-table in a ravel terrace west of the University buildings was satisfactorily and uickly determined, it was decided to use this method at Hennock using an lectrode-separation of more than a hundred feet.

The principle of resistivity measurement in the field is that four elecrodes, driven in a straight line and spaced at equal distances apart, are sed for electrical contacts with the ground. Electric current, generated by and in the 'Megger', is passed between the outer or *current electrodes.* he resulting voltage drop between the inner or *potential electrodes* is neasured and if I is the current in amperes, V is the voltage drop, and the round has a uniform resistivity ρ

$$\text{then } \rho = 2\pi \text{ a} \frac{\text{V}}{\text{I}}$$

$$= 2\pi \text{ a R}$$

vhere 'a' is the separation of the electrodes and R is the resistance measured etween the inner or potential electrodes.

Either of two methods is used in the field: a constant electrode-separation o that horizontal changes in electrical resistivity can be measured, or a entral electrode which gives variations of resistivity with depth. At Henock, resistivity determinations were made at the stations used for the magetic survey, i.e. constant electrode-separation. As the electric resistance of nicaceous haematite is very low compared with that of granite it was conidered possible that mineralised zones of low electrical resistivity could be etected in the granite. The values for resistivity traverses shown in Fig. 8 vere obtained by parties of three, using both 100 ft. and 250 ft. electrode-eparation and by moving the whole equipment (after several readings at ach position) at 10 ft. and 20 ft. intervals. Values obtained along traverse Io. 3 show remarkable agreement with those given by the variometer over ne same stations. Of special interest, however, is the fact that the displacenent of the trough in the lower traverse (250-foot electrode-separation) ives the inclination of the lode between these depths.

Finally, to check the accuracy of the method, the resistivity equipment vas set up along a known lode, using an electrode-separation of 100 ft. he values for resistivity obtained lay between 12 per cent and 15 per cent f those obtained across the lode. By rotating the electrode-line through 0° intervals from the line of the lode further values for the resistivity were btained. In the case when the electrode-line subtended 40° at the line of ne lode, the value of resistivity was over 80 per cent of that obtained on an lectrode-line oriented at 90° to the lode.

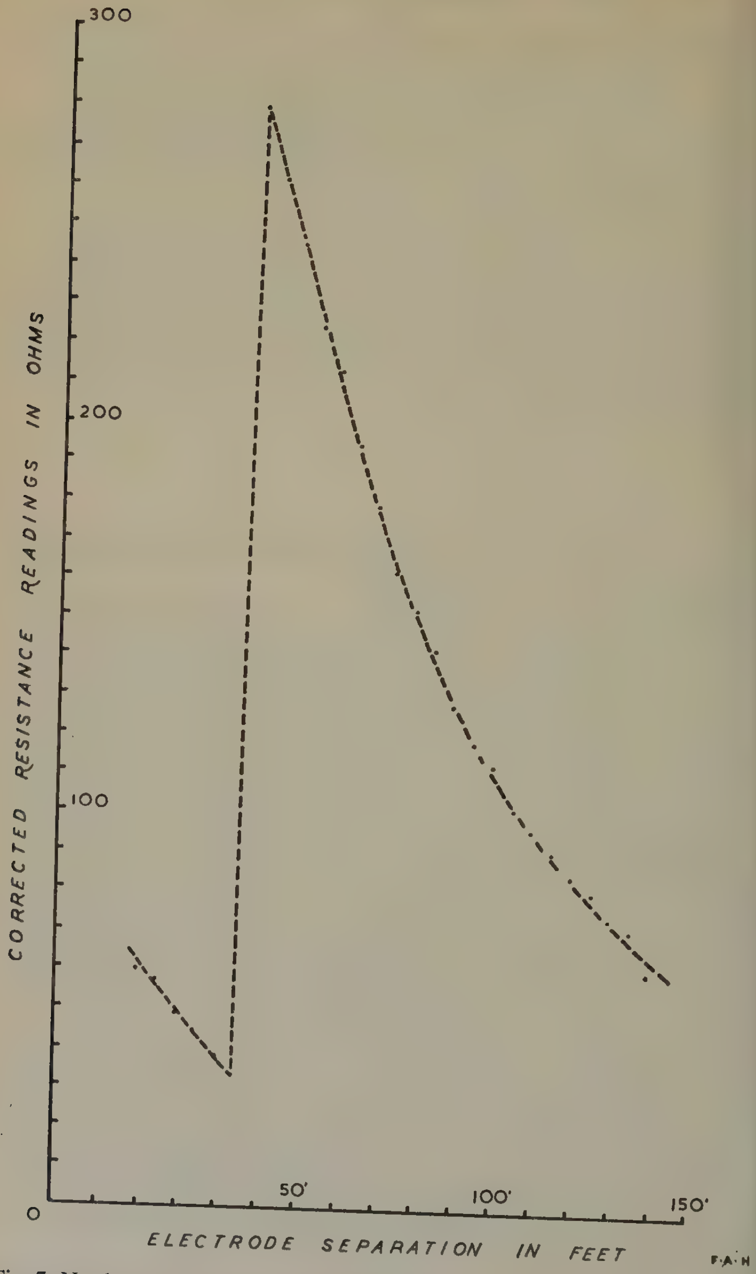
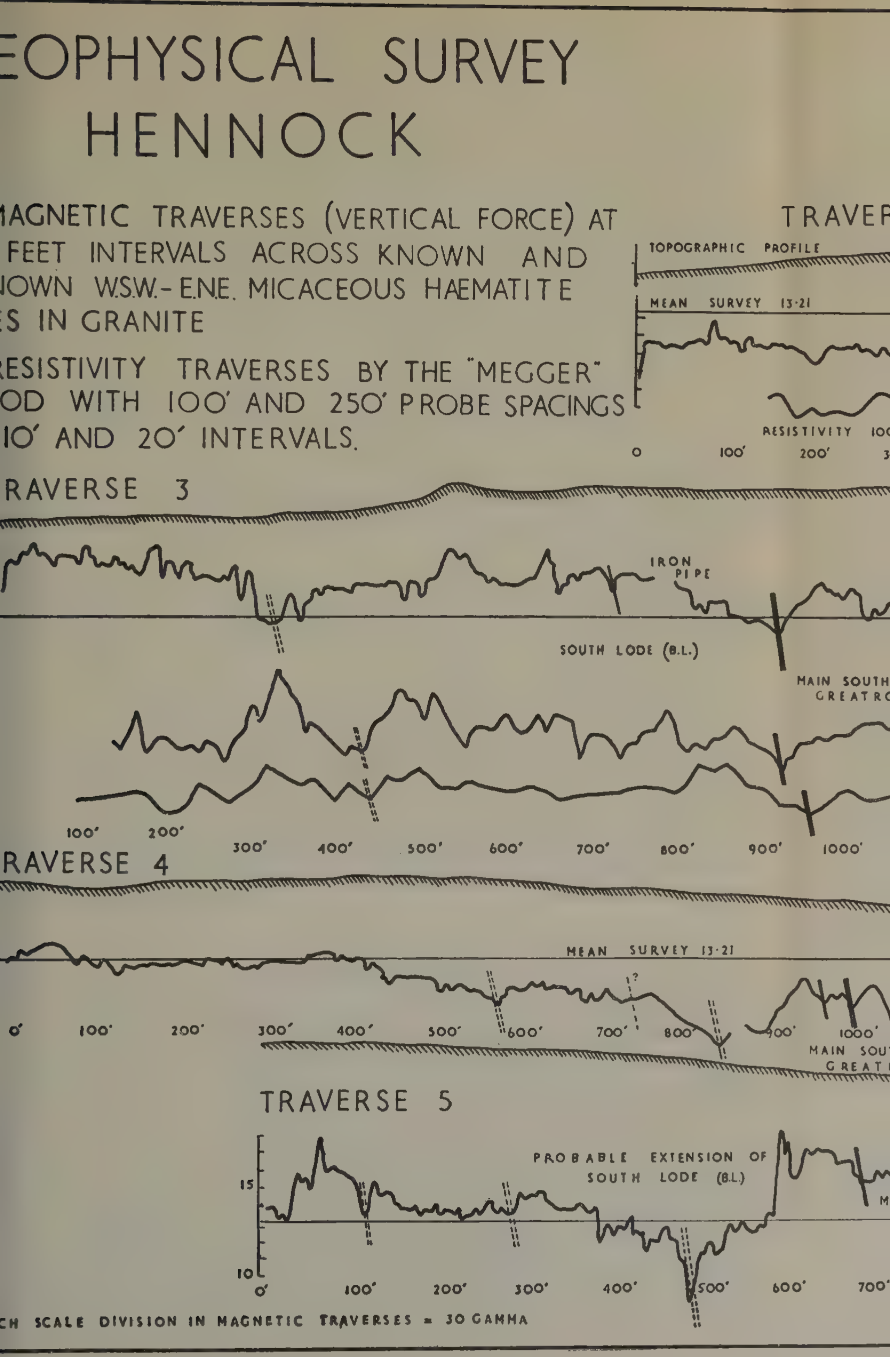


Fig. 7. North–south traverse, using increasing electrode separation across probable extension of Main Lode (Beedon Lane) on Traverse 4. Centre 1375 ft.


EOPHYSICAL SURVEY
HENNOCK
IAGNETIC TRAVERSES (VERTICAL FORCE) AT
FEET INTERVALS ACROSS KNOWN AND
IOWN W.S.W.-E.N.E. MICACEOUS HÆMATITE
ES IN GRANITE
RESISTIVITY TRAVERSES BY THE "MEGGER"
OD WITH 100' AND 250' PROBE SPACINGS
10' AND 20' INTERVALS.
TRAVEF
TOPOGRAPHIC PROFILE
MEAN SURVEY 13·21
RESISTIVITY 10C
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RAVERSE 3
IRON PIPE
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MEAN SURVEY 13·21
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700'
800'
900'
1000'
MAIN SOU
GREAT
TRAVERSE 5
PROBABLE EXTENSION OF SOUTH LODE (B.L.)
15
10
0'
100'
200'
300'
400'
500'
600'
700'
M
CH SCALE DIVISION IN MAGNETIC TRAVERSES = 30 GAMMA

Fig.

In the following year Mr. Devenish carried out a north–south traverse cross the probable lode indicated at 1375 ft. in traverse No. 4. In this raverse the central point was taken at 1375 ft. and increasing electrode-eparations from 20 ft. to 150 ft. were used. In Fig. 7 these readings are hown graphically. The most striking feature is the abrupt increase in esistivity between 40 ft. and 45 ft., after which the resistivity falls steadily. This anomaly indicates the lower level to which the granite is water-earing—not the presence of an ore body. By means of this method it is ery unlikely that even a four-ft. lode would greatly reduce the resistivity etween successive values for a series of five-foot increases in the electrode-eparation.

(c) **Radioactivity Survey.** Through the courtesy of Messrs. E. K. Cole Ltd., the author was able to use one of the new light-weight portable adioactive ore detectors manufactured by the company. The apparatus onsists of a well-protected tube, housing a geiger counter and a pair of arphones. The presence of radioactive ores is indicated by the number of clicks’ per minute heard by the observer in his earphones. In sedimentary ocks the background count was 70–80 per minute, whilst on the surface, n the Hennock area, the average count was 140–145 per minute. By moving long known micaceous haematite lodes, and also along traverses Nos. 1–5, o appreciable change in the count was observed. By repeating this pro-edure underground, no evidence was found of radioactive ores accom-anying the lodes although the count (160 per minute) was slightly higher han that on the surface.

One extremely useful application of the apparatus was revealed during his period, however. It was found that by traversing on the surface across ranite–sedimentary contacts there was an appreciable change in the counts nd therefore the instrument might have a further use in revealing contacts overed by soil and drift.

5. CONCLUSIONS

At the outset of this work it seemed that the chances of locating thin icaceous haematite lodes in this mineralised granite by magnetic and lectrical resistivity methods were slight. In Fig. 8 is shown a detailed ecord of all the geophysical prospecting carried out over a period of early seven weeks in August and September 1951. The traverses are orrectly orientated and their positions shown in the accompanying eological map (Fig. 3). However, it is now clear, from the results of this, e first geophysical survey in this area, that these methods can be used to cate the lodes under consideration with some degree of success. The bvious advantages of this method of prospecting are its speed and cheap-ess. It must be emphasised, however, that the results of geophysical prospecting are not entirely conclusive and must be supplemented by trenches on the surface and exploratory drilling underground.

The first important conclusion to be drawn from the foregoing results is that by using both methods of exploration it was possible to detect quite accurately from the surface, not only the positions but also the depths of underground lodes. Of the two methods employed, the variometer gives a more positive indication, e.g. in traverse No. 3 the Main South Lode (Great Rock) is shown by a progressive fall from 830 ft. to 930 ft. where it reaches its minimum.

Secondly, the size of the negative anomaly in the values of the vertical magnetic force indicates the size of the ore body. This is illustrated by reference to traverse No. 2 at 600 ft. Here the downward inflexion on the curve is small and corresponds to only a small lode at this point. Little ore was mined here in fact. The most productive part of this lode is farther east and below point 1375 ft. of traverse No. 3. Here the curve indicates quite a large negative magnetic anomaly. Electrical resistivity appears to give no real indication of the size of a particular ore body.

Thirdly, the records indicate zones of mineralisation where for parts of the traverse either the electrical resistivity is low or there is an area of low average value of V. Such values are interpreted (as in traverse No. 3 between 1500 ft. and 1700 ft.) as areas where the ore is disseminated throughout the rock in small veins or pockets which might not be profitable to work at the present time.

Finally, it is possible to obtain the inclination of a lode by the electrical resistivity method. On using different electrode-spacings, the dip of the lode is indicated by the displacement of the trough obtained by the greater electrode spacings. This is illustrated in traverse No. 3 where this displacement (to the north) is shown.

Since the completion of this survey, some trial pits have been put down where ore-concentrations seemed likely. Some revealed stringers of ore, but the marked trough at 375 ft. in traverse No. 3 was barren. This last may be due to the fact that the pit was opened at 375 ft. on the surface, whereas resistivity values show a marked inclination of the ore-body to the north. The main presumed extensions indicated in Fig. 8 should be proved at a later date. One encouraging development, from the geophysical viewpoint, is that a new lode has been developed from Great Rock which is on the line indicated by traverse No. 5 at 490 ft. A useful result of this survey has been to indicate barren ground as well as ore-bodies and one lode, which gave little indication of ore in traverse No. 4, is, in fact, no longer worked. Clearly, future geophysical work of this kind will need to be carried out in two stages. First, preliminary prospecting, to locate mineralised granite, and second, detailed traversing by both variometer and electrical resistivity equipment at small station intervals.

ACKNOWLEDGMENTS

The geophysical prospecting was carried out with the assistance of Messrs. J. T. Cumberlidge, A. R. Newton, D. Skinner and P. Stubbs. Technical assistance was given by Mr. R. Hendry who also prepared the rock sections. Mr. Sydney Taylor, Manager of the Great Rock Mine, gave invaluable advice and assistance at all times. To these, and to those others who helped in the successful completion of the geophysical prospecting, he author is extremely grateful. The author is also indebted to Dr. R. J. Firman for kindly reading the manuscript of this paper.

The work was made possible by a grant from the Department of Geology, University of Nottingham, and from the Ferrubron Mining Company Limited. The author wishes to express his especial thanks to Professor W. D. Evans for his invaluable assistance and particularly for promoting co-operation with the Directors of the Ferrubron Mining Co. Ltd.

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DISCUSSION

Dr. A. T. J. Dollar congratulated the author on an interesting paper of a kind not often presented before the Association. He welcomed the geophysical determinations and expressed the hope that their generally successful application to the problems described night encourage other field geologists to carry out similar work and offer the results to he Association.

He asked for further information about the type of variometer used in the magnetic determination on Dartmoor. Had the author encountered difficulties in reading the nstrument arising from gusty winds?

Also Dr. Dollar said he was interested to learn that the author had succeeded in determining the position of a granite contact by means of a Geiger counter and stop-watch, despite masking of the contact by a considerable thickness of boulder clay. Consequent upon preliminary traverses across comparable junctions on Lundy with his type of equipment, in 1930, the speaker had found, more recently, that a sensitive atemeter, or a scintillometer, was more satisfactory for such determinations. Had the uthor employed either of the latter instruments for this purpose, at any stage?

Dr. F. A. Henson thanked those present for their reception of the paper and Dr. A. T. J. Dollar for his kind remarks. The author stated that the two instruments used in the magnetic survey were Watts Vertical Force variometers. No difficulties had been experienced in using these instruments in the field during gusty weather, although the maximum elevation of the terrain was over 800 ft. O.D. It had been found, however, that the most satisfactory period of operation was in the forenoon, i.e. before diurnal development of heavy cumulus and showers. Usually, bad weather resulted in cessation of work on field traverses, the time being spent in plotting earlier work so that parts of traverses could be re-checked, if necessary. The author agreed with the speaker that a scintillometer would be of greater use in locating concealed contacts between igneous and country rocks, but both the portability and sensitivity of the instrument used was most satisfactory.

The Minor Intrusive Suite Associated with the Criffell–Dalbeattie Granodiorite Complex

by W. J. PHILLIPS

Received 9 March 1955

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ABSTRACT: The suite of minor intrusions associated with the Criffell–Dalbeattie granodiorite complex is composed of a great number of porphyrite and porphyry dykes which are the minor intrusive equivalents of the granodioritic rocks, and a relatively mall number of spessartite and kersantite lamprophyre dykes which were generally ntruded before the porphyrites. The petrography of the three groups of dyke-rocks is described and a comparison made between the chemical composition of the porphyrite and spessartite rocks and their hornblendes. It is suggested that high-temperature pessartite magmas developed from primary olivine basalt magma by reaction with ialic material at the roots of the Caledonian orogenic zone, and that the later passage of emanations along some of the consolidating spessartite dyke magmas effected the development of the kersantite dykes by extensive recrystallisation which continued after the consolidation of the dykes.

1. INTRODUCTION

THE EMPLACEMENT of the Lower Old Red Sandstone granitic complexes of he Southern Uplands of Scotland was accompanied by the intrusion of an xtensive suite of minor intrusions. Most commonly they form dykes which trend in two predominant directions, parallel, and almost at right angles to the trend of the Silurian sedimentary rocks, and are more abundant near the plutons. The western end of the Criffell–Dalbeattie complex was a focus for a great number of these and other intrusions. Numerous dykes of north-westerly trend have been intruded into the plutonic rocks of the complex and several thick multiple and composite intrusions occur to the south, along the Solway shore.

All the minor intrusions in the vicinity of the Criffell–Dalbeattie complex have sharp chilled contacts and occasionally xenoliths of wall rocks are enclosed in dykes. Generally flow orientation of the phenocrysts is not visible except within a few inches of the contact. Always the north-westerly dykes are nearly vertical but it is interesting to note that a great many of the cross-cutting dykes dip at about 70° north-east.

The minor intrusions fall into three petrological groups: the porphyrite–porphyry group, the spessartites, and a small number of kersantites. About 95 per cent of the minor intrusions are brown or grey, usually markedly porphyritic rocks which fall in the first group. Some of the lamprophyres are easily recognised in the field but many rocks are very dense and can be identified only in thin sections.

2. THE PORPHYRITE–PORPHYRY GROUP

(a) **Petrography.** Plagioclase of composition An_{25}–An_{35} is the characteristic phenocryst of the porphyrites and in some dykes it forms subhedral crystals up to 8 mm. in length. Most of these oligoclase–andesine crystals are clouded with kaolin and minute flakes of sericite in patches and sometimes in their outer zones. Some plagioclase phenocrysts show faint oscillatory zoning and a few enclose small crystals of hornblende, biotite and plagioclase.

A green hornblende is also a characteristic mineral of the porphyrites and forms subhedral or euhedral crystals, or glomeroporphyritic masses up to 3 mm. in length. The hornblende is pleochroic, X=pale yellowish-green; Y=grass green and Z=darker green, occasionally with a bluish tint. Its refractive indices are 1.650, 1.660 and 1.669 respectively, and the extinction angle $Z \wedge c = 23°–25°$. Sometimes the hornblende has been altered to chlorite, with some granules of epidote, sphene and magnetite. In one or two porphyrites small partly-altered grains of colourless pyroxene are present. In some of the darker, finely-crystalline porphyrites small flakes of biotite have developed at the edges of the hornblende crystals. Generally, however, biotite forms large phenocrysts which often enclose accessory minerals. The biotite has been altered to chlorite, sagenite and sphene in many dykes.

The ground-mass of the dykes of the porphyrite–porphyry group varies considerably in its degree of crystallinity. Some dykes have dense microcrystalline matrices, while in others the ground-mass consists of small crystals of oligoclase and graphically-intergrown patches of quartz and oligoclase. Tiny crystals of hornblende and biotite, and granules of zircon, apatite, sphene and magnetite often occur in the ground-mass. Frequently the plagioclase crystals have clear outer rims of a more albitic composition, while the central parts may be clouded with kaolin and sericite. Intergranular replacive pools of potash-felspar are usually present, and narrow rims of myrmekite have sometimes developed at the edges of the oligoclase crystals (Fig. 1, A).

Rounded, apparently resorbed grains of quartz form conspicuous phenocrysts in the more coarsely crystalline dykes, though they also occur in some of the finer-grained rocks. These dykes are termed quartz-porphyrites.

A number of dykes are characterised by the presence of microperthite phenocrysts which sometimes reach three-quarters of an inch to one inch in length, and these dykes are here described as granite-porphyries. The microperthite phenocrysts are usually bordered by a zone, 1 mm. wide, in which small oligoclase and biotite crystals, and net-like masses of optically continuous blebs of quartz, are enclosed. Apparently these zones result from replacement of the ground-mass. Hornblende is rarely present but biotite always occurs as phenocrysts in these rocks (Fig. 1, B).

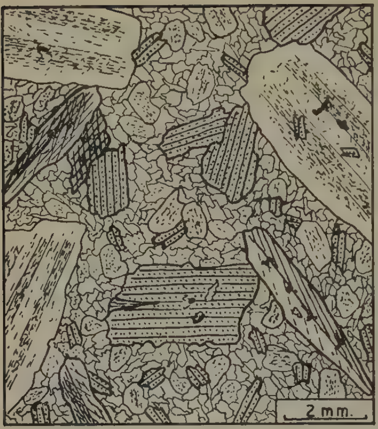
The ground-mass of the porphyries consists of small oligoclase laths, usually with albitic margins, intergranular quartz and potash-felspar, and patches of graphic intergrowths. Small biotite laths occur in the ground-mass and in one dyke a few flakes of muscovite have developed by replacement of the other minerals.

(b) **Albitisation.** The primary minerals of many porphyrites have been altered but in some dykes the replacement by secondary minerals has been extensive. The oligoclase–andesine phenocrysts have been partly replaced by granules of yellowish epidote and irregular blebs of albite and sometimes quartz. The central parts of some thick intrusions have been completely altered and almost all the oligoclase has been replaced by albite with minute flakes of sericite and small masses of yellow epidote. 'Ghosts' of the original plagioclase phenocrysts remain. The primary mafic minerals have been completely altered to penninite with small granules of brownish epidote and magnetite. Calcite occurs in the form of late replacing masses. The final result of these alterations has been termed albitophyre by King (1937) and the development of such rocks may be summarised as follows:

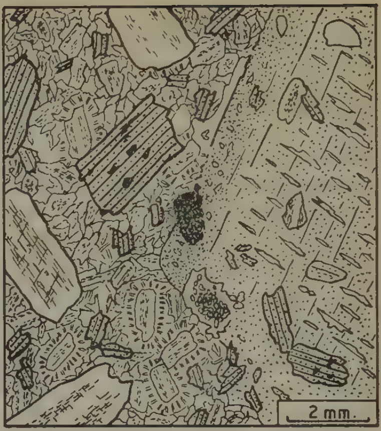
(i). Chloritisation of the mafic minerals, with the release of small granules of brownish epidote, quartz and calcite:

(ii). Breakdown of the plagioclase to granules of yellowish epidote and blebs of albite, with the release of some calcite and sericite:

(iii). Late calcite replacements of the other minerals.



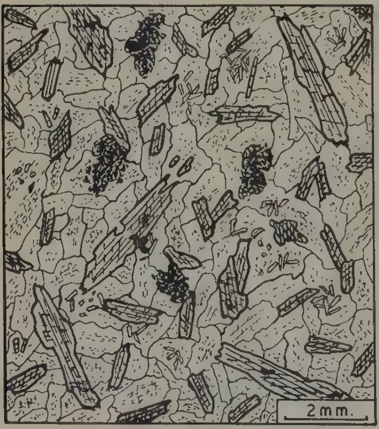
A



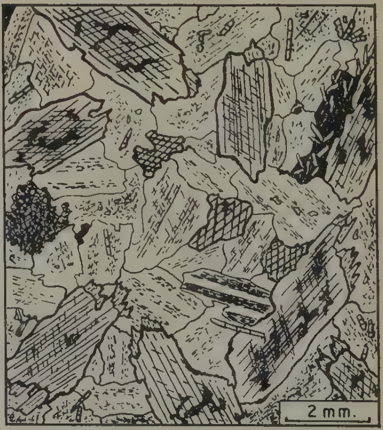
B

A. Hornblende–biotite porphyrite.

B. 'Granite-porphyry', with large phenocryst of microperthite, biotite and small altered crystals of oligoclase, often rimmed by myrmekite, in a ground-mass rich in quartz and graphic intergrowths.



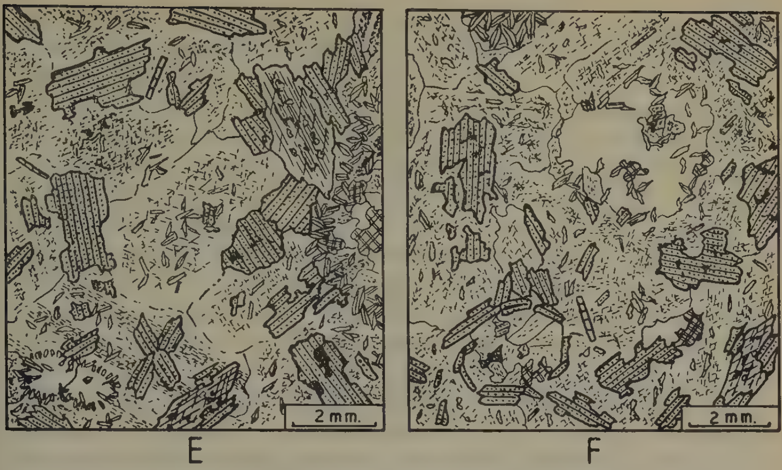
C



D

C. Fine-grained spessartite, composed of intergrown laths of brown hornblende and oligoclase–andesine, with some clots of chlorite.

D. Coarse basic spessartite (155), with large crystals of brown hornblende often edged by green amphibole and replaced by tremolite.



E. Kersantite, with some hornblende pseudomorphs and plates of biotite and innumerable flakes of tremolite lying in a ground-mass of ill-defined oligoclase. The edge of a vesicle, rimmed by tremolite flakes and filled with oligoclase, chlorite, quartz and calcite, occurs on the right.

F. Kersantite, with an irregular mass of quartz partly replaced by tremolite and albite, and a small vesicle filled with oligoclase and rimmed by biotite.

Fig. 1 A–F. Microscopic details of minor intrusive rocks in the Criffell–Dalbeattie granodiorite complex

Only water and carbon dioxide were required to effect such a breakdown of the primary minerals and therefore the agency was most probably residual hydrothermal solutions of the dyke magma. Complete albitisation, however, would require an addition of sodium and silicon, and it appears that the albitophyres occur where the residual solutions are most likely to supply a sufficient amount of these ions, i.e. in the centre of the thicker intrusions. King has already expressed the opinion that this characteristic hydrothermal alteration of the primary minerals was brought about by a process of autolysis through residual solutions which were rich in water, carbon dioxide, soda and silica.

3. THE SPESSARTITE GROUP

Dyke-rocks of the second most important group are composed of oligoclase–andesine and brown hornblende, with some chloritic clots and small interstitial amounts of quartz. Generally these rocks have a distinctive texture resulting from the intergrowth of plagioclase laths and prisms of brown hornblende, but porphyritic types are common and phenocrysts of hornblende, and also plagioclase, are sometimes abundant.

(a) **Petrography.** Near Thornyhill farm, about half a mile north of Portowarren, there is an ill-defined outcrop of a coarse-grained spessartite which consists of an intergrown mass of pinkish felspar and prisms of hornblende up to 8 mm. in length.

The hornblende is pleochroic, X=light brownish-yellow; Y=yellowish-brown and Z=dark reddish-brown, with absorption $Z > Y > X$, and extinction angle $Z \wedge c = 15°–18°$. The refractive indices are 1.644, 1.660 and 1.676 respectively. The central part of many crystals is occupied by a dull green hornblende with some granules of sphene and occasionally magnetite. Penninite has developed at the edges of some of the hornblende crystals and a few show a gradation into a narrow rim of pale green tremolitic amphibole. Large masses of fibrous chlorite, occasionally enclosing some flakes of antigorite, are present.

The other essential mineral is plagioclase, of a composition ranging between An_{25} and An_{35}. It forms intergrown anhedral laths which are partly altered to kaolin, sericite and occasional granules of epidote. A few small intergranular pools of quartz and potash-felspar are present and are often conspicuous amongst the clouded plagioclase laths. Minute rims of myrmekite are developed at the edges of some of the plagioclase crystals. Apatite is a prominent accessory mineral and forms long needles which often cut across the boundaries of the hornblende and plagioclase (Fig. 1, D).

In this coarse spessartite it appears that the brown hornblende has been partly altered to a pale, dull green hornblende, with the release of granules of sphene. A pale greenish amphibole has developed by replacement at the edges of some brown hornblende prisms. The chloritic clots may represent the final stage of alteration of the hornblende but in some cases they appear to be pseudomorphs of olivine.

The other spessartite dykes of this suite are fine-grained, dark brown rocks in which hornblende prisms up to 3 mm. long and sparse phenocrysts of pink plagioclase occur with chloritic clots (Fig. 1, C).

The hornblende is pleochroic, X=brownish-yellow; Y=deep yellow brown and Z=reddish brown. The refractive indices are 1.632, 1.644 and 1.661 respectively, with the extinction angle $Z \wedge c = 12°–14°$. This brown hornblende occurs in two habits, as subhedral phenocrysts and as numerous stumpy prisms in the ground-mass. Often the edges and cleavages of the hornblende have been altered to a fibrous tremolite, sometimes with the release of granules of sphene. The hornblende has also been altered to a pale green penninite which occasionally forms distinct crystals and is associated with grains of sphene and a few larger grains of brown epidote. Clots of fibrous chlorite are often conspicuous in hand specimen, and in thin section they are sometimes seen to be accompanied by grains of epidote and sphene. Small ragged laths of tremolite and partly altered prisms of brown hornblende are often enclosed in the clots. In one dyke small euhedral crystals of pyroxene have been completely pseudomorphed by chlorite.

The ground-mass of the dykes usually consists of a distinctive intergrowth of oligoclase–andesine laths, though in many dykes similar plagioclase forms phenocrysts up to 3 mm. in length. Often the plagioclase is partly clouded with kaolin and sericite, but commonly the crystals have clear outer rims. Quartz is present in most dykes but usually occurs only as very small intergranular pools which are seen to replace the margins of the adjacent plagioclase crystals. Minute intergranular replacing pools of potash-felspar are present in some of these rocks. Calcite occurs in most dykes and forms small irregular grains which have replaced the other minerals.

In two spessartite dykes on Bengairn, some small flakes of biotite and a number of segregations of quartz grains occur with a brown hornblende which is very similar to those of the normal spessartites (Table II, p.116). The biotite flakes usually border the quartz segregations and are also seen to replace the brown hornblende prisms which show an alteration to a green amphibole.

Many of the sepssartite dykes enclose rounded xenoliths of finer-grained spessartite rock in which there is generally a greater proportion of hornblende.

(b) **Albitisation.** In most of the spessartite dykes the brown hornblende shows an alteration to a green variety and occasionally to tremolite with sphene and epidote granules, but in some dykes the plagioclase has been almost completely replaced by granules of yellowish epidote and blebs of albite and quartz. In some rocks this epidote forms radiating prisms 1 mm. long in segregations of quartz. The sequence of the development of the secondary minerals appears to be:

(i). Conversion of brown hornblende to pale green tremolitic hornblende, with release of sphene:

(ii). Alteration of hornblende to chlorite and brown epidote grains:

(iii). Breakdown of the oligoclase–andesine to yellowish epidote granules and albite:

(iv). Development of replacing masses of quartz and prisms of yellowish epidote:

(v). Calcite replacement.

This breakdown of the primary minerals of the spessartites was probably effected by the passage of residual solutions from below. It is interesting to note the close similarity of these alterations with those observed in the porphyrites. In both groups of dykes the residual solutions appear to have been rich in volatiles and soda.

(c) **Vesicles.** Two of the spessartite dykes which have been studied have small sharply-defined vesicles, up to 3 mm. in diameter, scattered throughout the rock. The simplest form of vesicle-filling consists of intergrown laths of oligoclase–andesine which are slightly larger than the laths in the enclosing rock. These areas are usually elliptical in shape and are often devoid of any other mineral. Tangential biotite flakes bordering vesicles have been observed in one spessartite. Irregular grains of clinozoisite occur throughout the rock and larger masses are seen to replace the plagioclase in the vesicles. More commonly, however, the plagioclase is replaced by large crystals of calcite.

In one dyke, elliptical vesicles are filled with plagioclase laths accompanied by crystals of pale green penninite which are sometimes bordered by what appears to be a dull cryptocrystalline chlorite. Granules of brownish clinozoisite are also associated with the chlorite vesicles. In the same dyke the central part of a number of plagioclase vesicles is occupied by radiating prisms of clinozoisite which are partly replaced by calcite. One plagioclase-filled vesicle with patches of dull brown clinozoisite is replaced, in turn, by pale green penninite, calcite and finally by haematite which has crystallised along the borders between the calcite and the chlorite.

(d) **The Granophyric Spessartite of Newmains.** Kennedy & Read (1936) have described an interesting lamprophyre at Newmains, approximately four and a half miles north-north-east of Loch Arthur, at the north-eastern end of the Criffell–Dalbeattie complex. The dyke is a granophyric spessartite or 'markfieldite', and the normal rock consists of abundant prisms of brown hornblende with clouded, tabular oligoclase crystals and some intergranular quartz, potash-felspar and graphic intergrowths. This spessartite is closely related to the normal spessartites and consequently is regarded as an integral member of the minor intrusive suite of Lower Old Sandstone age.

However, the Newmains dyke is of particular interest because it contains some parts relatively rich in mafic minerals and also irregular patches and veins of a leucocratic type which consists of the same minerals as the normal rock but is generally coarser in texture and has rather more intergranular quartz and orthoclase. Unlike the other minor intrusions, the granophyric spessartite has caused a considerable thermal metamorphism, and in places a potash enrichment of the country rocks within six feet of the contact. Normally the contact of the dyke is sharp, but where the leucocratic variety comes in contact with the greywackes there has been a considerable amount of contamination and assimilation, causing the renewed crystallisation of much diopside and in places porphyroblasts of brown hornblende. A number of fine-grained aplitic veins cut the dyke and resemble the leucocratic variety except in texture. In the country rocks the aplites consist of albite-oligoclase with no intergrowths.

4. THE KERSANTITE GROUP

(a) **The More Crystalline Dykes.** Some six miles south of Dalbeattie, in the small bay 400 yds. north of Castle Point, a compact, fine-grained, porphyritic spessartite is chilled against a dark mica-lamprophyre. This mica-lamprophyre trends east-north-east, and is exposed at a number of points on the shore, though it is crossed by the spessartite which forms a wall-like outcrop about five feet in width. Several thin spessartite dykes are exposed on the north side of the two dykes.

The kersantite is quite distinctive in hand specimen, consisting of black, shiny flakes of biotite, 2 mm. across, pinkish felspar and clots of chloritic material with scattered vesicles 6 mm. in diameter.

In thin section many irregularly shaped laths of biotite are seen to be scattered in a coarsely intergrown mass of ill-defined, un-twinned oligoclase crystals in which innumerable flakes of chlorite and tremolite are embedded. The biotite laths have irregular, often sutured edges, and frequently lie completely within or across the boundaries of the plagioclase crystals, suggesting that the biotite has crystallised at least in part, by the replacement of the plagioclase. Pseudomorphs of hornblende, which are often euhedral or subhedral in form, are composed of a slightly greenish tremolite which is usually accompanied by granules of sphene, small irregular patches of calcite and sometimes by a pale chlorite. One tremolite pseudomorph was replaced by a few fine stringers of quartz. Small flakes of biotite have developed by replacement at the edges and sometimes in the centre of these pseudomorphs. Many of the small porphyroblastic plates of biotite are bordered by minute granules of sphene and possibly epidote.

The individual oligoclase crystals are usually relatively large and many are 4–5 mm. in length. Their borders are usually albitic, and because of this and the development of secondary minerals they are often ill-defined. Although usually there is a gradation from the centre into the albitic outer zone, some oligoclase crystals are replaced by albite which extends as stringers into the centre of the crystal. Irregular blebs of albite are also associated with the development of small laths of sericite in some parts of the oligoclase crystals. In some parts of the dyke this albitisation has proceeded to a more advanced stage with the crystallisation of much quartz and calcite, and the alteration of the biotite to chlorite. Innumerable small laths and crystals of tremolite, many accompanied by sphene granules and apparently secondary after hornblende, are also embedded in the oligoclase crystals. Long needles of apatite are present. Some small intergranular replacement pools of potash-felspar occur but are relatively rare.

Grains of quartz 1–2 mm. in length occur and are usually surrounded by reaction rims 0.1 mm. in width, though a few small intergranular patches of quartz are present in the rock (Fig. 1, E). Sometimes the quartz grains are composed of two crystals and many have irregular edges due to replacement by albite which sometimes also forms irregular patches within the crystals. Greenish tremolite flakes occur at the edges of the quartz grains and often extend into the crystals by replacement, as does the albite and calcite which accompanies them. Other grains of quartz appear to have been completely replaced by colourless laths of tremolite, with patches of albite, calcite and, rarely, some pale chlorite (Fig. 1, F). The evidence suggests, therefore, that the quartz grains are xenocrysts which have been incorporated by the magma which gave rise to the dyke, and have been replaced progressively by secondary minerals.

Vesicles are abundant in some parts of this kersantite. In thin section some of the smaller vesicles are seen to be composed of intergrown laths of clouded, pink-stained oligoclase with replacement blebs of fresh albite. Usually the vesicles are elliptical in shape and are often bordered by tangentially-oriented biotite flakes. It is interesting to note that these flakes often cut across an oligoclase crystal, indicating that the plagioclase of the vesicle sometimes grew in optical continuity with that of the enclosing rock. Larger vesicles often have a central portion of matted, greenish tremolite prisms, with quartz occurring in the intergranular spaces. Calcite was the last mineral to crystallise in many of the vesicles, but in a few cases haematite is seen to be later than the calcite.

Two other dykes, very similar to the one just described, outcrop on the shore north of Castle Point, while another outcrops in the cliffs east of Portling and several others occur just west of Bengairn.

(b) **The Porphyritic Kersantite Dykes.** There are several dykes which are petrologically similar to the coarsely-crystalline kersantites but much finer in texture and generally containing numerous phenocrysts of quartz, plagioclase, biotite and pseudomorphs of hornblende.

The quartz grains are often irregular and rounded in shape, and appear to have been partially resorbed. The edges of the grains are seen to be replaced by albite which forms irregular blebs within many of the quartz crystals. Narrow reaction rims of calcite surround some of the quartz grains. Tabular grains of oligoclase–andesine, up to 3 mm. long, are often present and usually have rounded margins. These plagioclase grains are bordered by narrow but conspicuous reaction rims in which the plagioclase has been replaced by albite and minute flakes of sericite. Many of the plagioclase laths are complex and formed of two or more crystals; some are zoned and a few enclose grains of biotite and hornblende.

The pseudomorphs of hornblende are often euhedral in shape and consist of pale chlorite, much calcite and innumerable minute granules of epidote and sphene. Laths of tremolite are sometimes present. Biotite has developed at the edges of some of the pseudomorphs, and small laths are cattered throughout the ground-mass of plagioclase, apparently havings crystallised after replacement of these minerals. Biotite also forms large phenocrysts which often show bent cleavage plates. Some of the biotite grains are bordered by narrow reaction rims, and many appear to have been corroded and resorbed.

These phenocrysts are distributed irregularly in the fine-grained kersantites and since the great majority of them appear to show the effects of resorbtion it is concluded that they are xenocrysts incorporated by the magma. Many of the dykes enclose groups of two or more crystals, and in some cases small xenoliths of more crystalline rock are present.

5. THE AGE RELATIONS OF THE MINOR INTRUSIONS

The porphyrite group of dykes appears to span the period of granodiorite emplacement, some of these injections being truncated by the granodiorites while many are intruded into the outer non-porphyritic granodiorite of the main Criffell–Dalbeattie pluton. The granite-porphyries were the last members of this group to be intruded, since they are the equivalents of the central porphyritic granodiorite.

Generally the spessartites appear to be early and many are cut by porphyrite intrusions which are chilled against them. Spessartite dyke-rocks occur as screens between many of the numerous porphyrite intrusions exposed on the shore north of Castle Point, although one spessartite is chilled against an early porphyrite. Early spessartite dykes are also present at the focus of minor intrusions west of Bengairn, and some spessartites occur in the Bengairn quartz-diorite. Several finely-porphyritic spessartites were intruded into the porphyritic granodiorite which forms the centre of the Criffell–Dalbeattie pluton. These dykes have been sheared into lenticular masses by movements along vertical planes of north-west trend which must have taken place soon after the end of the plutonic activity.

It appears, therefore, that the spessartite dykes were intruded mainly before the great number and bulk of porphyrite intrusions. However, spessartite magma was available for intrusion after the final consolidation of the Criffell–Dalbeattie pluton, and possibly also in the period between the consolidation of the Bengairn quartz-diorite and the emplacement of the main pluton.

Xenoliths of kersantite occur in many porphyrite intrusions and several porphyrites have been chilled against kersantite dykes. A number of cases in which spessartites and kersantites are chilled against each other have been observed, but there does not appear to be any sequence of intrusion except in the sense that both preceded the porphyrite intrusions.

6. A COMPARISON OF THE CHEMICAL COMPOSITIONS OF THE SPESSARTITE AND PORPHYRITE DYKE-ROCKS AND THEIR HORNBLENDES

Petrologically the two groups of dyke-rocks are quite distinct, and intermediate rocks are absent, though there are several rocks which are not easily classified on account of alteration. Apart from their fundamental differences there are a number of interesting comparisons to be made between the spessartite and porphyrite minor intrusions. In the first place both consist essentially of a hornblende and oligoclase–andesine, though the porphyrites also have much free quartz and usually biotite. Secondly, the breakdown of the plagioclase to epidote, albite and quartz has occurred in both rock-types, suggesting that the residual liquids were rich in the same constituents—volatiles and alkalies. Associated with this breakdown of the plagioclase is the alteration of hornblende to chlorite and epidote, while in the spessartites this alteration appears to have been preceded by the conversion of brown hornblende to a green variety.

In order to determine any relation between the chemical compositions of the two groups of rocks and their characteristic hornblendes, five chemical analyses were carried out by Dr. Sinha at the Imperial College of Science and Technology, London. These analyses, supplemented by others given by M. MacGregor (1937), Kennedy & Read (1936), and Tomkeieff (1937), are shown in Table I.

The porphyrite (1) and the granodiorite (2) analysed by MacGregor are seen to be very similar in composition although the porphyrite is richer in silica and probably represents one of the later members of the porphyrite–porphyry series.

The spessartites (3), (4) and (5) are all less rich in silica than the granodiorite although the Newmains dyke is much richer in silica than the normal spessartites. Furthermore, they are slightly less rich in alumina but are distinctly richer in magnesia, ferrous oxide and lime, and to a less extent in titania and ferric oxide. The water content of the rocks is variable but while the spessartites have an equivalent amount of soda, they have a smaller content of potash than the granodioritic rocks.

For comparison, the average analysis of the Scottish Carboniferous olivine-basalts, as given by Tomkeieff, is included. From this it can be seen that there is a closer relationship between the composition of the spessartites and the olivine-basalt than between the spessartites and granodioritic rocks. It is clear that there is a marked discrepancy in the variation of the content of magnesia and to a less extent of alumina and titania in the spessartites and the granodioritic rocks.

Of particular interest in a study of the porphyrite and spessartite minor intrusions is the difference in colour of their respective hornblendes. The

TABLE I: **Chemical Analyses of Criffell–Dalbeattie Rocks and Minerals**

	1	2	3	4	5	6	7	8	9
SiO_2	67.11	62.76	55.17	51.30	50.83	47.10	49.40	46.25	42.90
Al_2O_3	15.46	15.99	13.90	14.58	14.00	15.80	8.13	10.02	11.67
Fe_2O_3	1.21	1.55	1.19	2.39	2.11	4.00	1.80	2.01	2.20
FeO	1.87	2.78	4.39	4.82	5.05	8.30	8.16	7.74	7.99
MnO	0.06	0.08	0.17	0.13	0.15	0.20	0.24	0.27	0.24
MgO	1.81	2.87	8.37	6.97	8.10	7.40	14.24	14.13	13.54
CaO	2.46	3.56	5.02	8.70	8.74	9.40	11.75	10.60	11.30
Na_2O	4.34	3.92	4.53	3.76	4.80	3.10	0.83	1.01	1.58
K_2O	4.04	4.02	2.83	3.02	1.56	1.30	1.28	2.67	1.54
TiO_2	0.42	0.85	1.56	1.51	1.25	2.90	0.82	1.65	2.75
P_2O_5	0.28	0.32	0.22	0.76	0.44	0.50	0.39	0.36	0.12
H_2O	0.89	1.37	2.97	1.97	3.14	—	2.98	2.78	3.27
	99.95	100.07	100.32	99.91	100.17	100.00	100.02	99.49	99.10

1. Porphyrite near Craignair Quarry, Dalbeattie, *after M. MacGregor* (1937).
2. Hornblende granodiorite (G1), *after MacGregor.*
3. Granophyric spessartite, Newmains, *after Kennedy & Read.*
4. Fine-grained spessartite (416), Thornyhill, near Portowarren. *New analysis.*[1]
5. Coarse spessartite (155), Thornyhill, near Portowarren. *New analysis.*[1]
6. Average olivine basalt of Carboniferous age, *after Tomkeieff.*
7. Green hornblende from the main Criffell–Dalbeattie granodiorite (115), Kipp quarry. *New analysis.*[1]
8. Brown hornblende from the fine-grained spessartite (416). *New analysis.*[1]
9. Dark brown hornblende from the coarse spessartite (155). *New analysis.*[1]

optical properties of five representative hornblendes are shown in Table II, from which it can be seen that there is a close correspondence between the optical constants of the green hornblendes of the granodiorite and the porphyrite, and also between the brown hornblendes that occur in the spessartites 'C' and 'D'. Although the birefringences of both pairs of hornblendes are similar, the refractive indices of the brown hornblendes are lower than those of the green hornblendes. On the other hand the dark brown hornblende of the basic spessartite has a greater birefringence and the refractive indices embrace those of the green hornblendes.

The most outstanding feature of the hornblende analyses (7), (8) and (9) in Table I, is that the brown hornblendes are poorer in silica and richer in alumina than the green hornblende. The magnesia content of the three hornblendes exceeds the content of lime which, in turn, exceeds those of ferrous and ferric oxides. There is little variation shown by these oxides in the hornblendes, although there is a marked decrease in their amount in the granodioritic rocks. The brown hornblendes are rich in titania, which

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[1] The new analyses, 4, 5, 7, 8 and 9 were carried out by Dr. Sinha at the Imperial College, London.

TABLE II: Optics of Hornblendes from the Porphyrite and Spessartite Minor Intrusions of the Criffell–Dalbeattie Granodiorite Complex

		A	B	C	D	E
PLEOCHROISM	X	pale yellowish green		brownish yellow		light brownish yellow
	Y	grass green		yellowish brown		yellowish brown
	Z	darker green		dark brown		dark reddish brown
REFRACTIVE INDICES	α	1.645	1.650	1.632	1.635	1.644
	β	1.658	1.660	1.644	1.647	1.660
	γ	1.670	1.669	1.661	1.662	1.676
BIREFRINGENCE		0.025	0.019	0.029	0.027	0.032
$Z \wedge c$		23°–25°	23°–25°	12°–14°	12°–14°	15°–18°
2V		65°	60°–65°	large	large	large

A. Green hornblende from the granodiorite (115), Kipp quarry. *Analysis* 7.
B. Green hornblende from the porphyrite, Bainloch Hill.
C. Brown hornblende from the fine-grained spessartite (416). *Analysis* 8.
D. Brown hornblende from a spessartite with some biotite. Bengairn.
E. Dark brown hornblende from the basic spessartite (155). *Analysis* 9.

reflects its prominence in the spessartite magmas. The brown hornblendes also contain more soda than the green variety and appear to be slightly richer in potash although the latter is probably related to the potash-content of the spessartite magmas. There is no difference in the water-content of these particular hornblendes. Consequently, in deficiency of silica and richness of titania and the alkalies, the brown hornblendes reflect the composition of the spessartite magmas.

A close comparison can be drawn between the hornblendes under consideration and those studied by W. A. Deer from the appinites and diorites of the Glen Tilt complex. Deer came to the conclusion that the colour-change is not related to one factor, such as the oxidation of the iron or increase of titanium, but rather to the state of the ions in the hornblende structure and possibly to the state of oxidation of the titanium. These factors are not only related to the composition of the enclosing rock or magma, but probably depend to an even greater extent upon the temperature of crystallisation. Barnes has shown that common green hornblende changes to oxy-hornblende at about 800°C., and that the chemical change involves a loss of hydrogen, not water, at the time of oxidation of the iron. Kozu, Yoshiki & Kani have recorded the transformation of common green hornblende to a basaltic hornblende, with loss of water, at 750°C. It is concluded, therefore, that the early crystallisation of brown hornblende in the spessartites is related not only to the composition of the magma but also to its relatively high injection temperature.

7. THE PETROGENESIS OF THE LAMPROPHYRES

Lamprophyres of varying composition frequently occur in association with granodiorite complexes, and in consequence it has been suggested that the lamprophyres and aplites are the result of some process of contrasted differentiation of the granodiorite magma. However, in the Criffell–Dalbeattie complex the aplites are confined to the granodiorite and to the immediate contact zone, and were intruded just after the consolidation of the granodiorite, whereas the lamprophyres involve a much wider range in both time and space. The aplites can be related to the last stages of crystallisation and consolidation of the granodiorite magma, but the suggestion that the spessartites are a complementary differentiate of the granodiorite is not plausible in this particular area.

Because of its interesting petrology, and the marked effect it has had upon the adjacent greywackes and shales, the Newmains granophyric spessartite has been allotted a key position in the development of the Caledonian dyke suite.

Kennedy & Read (1936) concluded that the pegmatitic and basic varieties of the Newmains dyke were formed by the differentiation of the normal spessartite magma. They point out that because of the presence of olivine and nepheline in the norms of these rocks, the granophyric residue cannot be due to an original excess of silica in the magma. Furthermore, it cannot be accounted for entirely by the early separation of monoclinic pyroxene or hornblende in excess of their stoichiometric proportions, even when allowance is made for the under-saturation of igneous hornblendes. The only other mineral sufficiently poor in silica to affect the concentration of silica in the residual liquid is the white mica which was formed during the alteration of the plagioclase. Therefore Kennedy & Read suggested that the crystallisation of free quartz was related to the breakdown of the original plagioclase to albite, epidote, calcite and quartz, on account of its reaction with the residual liquid. This albitisation of the plagioclase has been observed in many of the spessartites of the Dalbeattie area and has been even more active in the porphyrites, the rock being converted into an albitophyre. Consequently this explanation of the granophyric intergrowths has a sound foundation, but whether it can account for all the quartz in the Newmains dyke is doubtful; especially when one considers the nature of the normal spessartites.

Dr. D. Reynolds has put forward an alternative hypothesis that the pegmatitic spessartite of Newmains is due to the assimilation, metasomatism and rheomorphism of quartz xenoliths by alk-aluminous emanations. While undoubted quartz xenoliths occur in the Newmains dyke, and in a few other spessartites of this suite, the metasomatism and rheomorphism of quartz xenoliths at Newmains is unconvincing. On the evidence of the Kirkcubbin (Ards Peninsula) and Newmains dykes, Dr. Reynolds has advanced the hypothesis that the whole of the Caledonian dyke suite, including peridotite, lamprophyres, porphyrite and porphyry, can be related to basic 'magmatic' material with associated alk-aluminous emanations and incorporated sialic material. While this combination provides a promising mechanism for the development of the varied lamprophyric magmas, the continuation of the processes to include the porphyrite–porphyry series of minor intrusions is unlikely and unnecessary since there can be no doubt that the latter dykes are the minor intrusive equivalents of the granodioritic magmas.

Extensive volcanic activity occurred in Lower Old Red Sandstone times, generally before the emplacement of the plutonic complexes, and since the great majority of flows consist of olivine basalt, with pyroxene andesite as the second most abundant type, it is important to examine the possibility of the derivation of spessartite magma from primary olivine-basalt magma. It is clear that a spessartite magma could not have been produced by fractional crystallisation of olivine-basalt magma, nor by the simple addition of sialic material to such a parent magma. While ferrous and ferric oxides, lime and titania decrease as is to be expected, there is a slight increase in the content of magnesia in the spessartites as compared with that in the olivine-basalt. Furthermore, the spessartites show a slight decrease in the content of alumina and a rapid, though variable increase in soda and potash.

Nevertheless, assuming that a high-temperature magma of olivine-basalt composition was in existence near the deeper zones of the Caledonian orogenic belt during the closing stages of the orogeny, it is conceivable that the intermittent, forceful upward migration of pockets of this magma through sialic material may have allowed of marked changes in the composition of the magmas. Although it is necessary to assume that the spessartite magmas retained a relatively high temperature until their final consolidation, a slow rate of cooling is not a serious problem in this environment since the sialic material was probably undergoing an increase in temperature which accompanied regional metamorphism and the development of the granodioritic magmas. While a basaltic magma loaded with olivine crystals could have accomplished a limited amount of fusion of sialic material, it is considered that reaction between the liquid portion of the magma and the enclosing rock could have effected the change in composition towards that of the spessartite dykes. The change may have been brought about by the replacement of silicon, sodium and potassium in the wall-rocks by aluminium and calcium from the magma. The loss of aluminium by the magma may have been balanced, in part, by an incorporation of aluminium and magnesium from the wall-rocks due to displacement by iron and manganese. The similar magnesia content of both the olivine-basalt and the spessartites may be largely accounted for by postulating the retention of most of the magnesium in olivine and possibly in some pyroxene crystals which could have escaped extensive reaction with the changing liquid poriton of the magma because of a high temperature. However, with a slow fall in temperature and changing composition of the magma, olivine would have become unstable, and if the MgO/FeO ratio of the magma had been markedly increased, brown hornblende may have crystallised in preference to a pyroxene. When the magmas eventually migrated upwards along vertical fractures they consolidated relatively quickly as dyke-rocks consisting of an intergrown mass of brown hornblende prisms, often in two habits, and tabular oligoclase–andesine crystals. Clots of chlorite, with some flakes of antigorite, may represent pseudomorphs of original olivine and pyroxene crystals, but a rapid fall in temperature allowed only a partial transformation of the brown hornblende to a green variety. In most dykes the residual solutions, more or less rich in volatiles, sodium and silicon, caused a partial breakdown of the primary minerals to albite, epidote, chlorite and calcite. In some spessartites probably the crystallisation of a small amount of biotite is related to the richness of the magma in potash and water. Undoubtedly the late-stage alterations were accentuated by the passage of volatiles from lower, still unconsolidated portions of the dyke while the final extensive calcite replacement which occurred in many of the dykes must have been effected by the passage of carbon dioxide.

The Newmains spessartite is particularly rich in silica at the expense of lime, a condition possibly resulting from a prolonged reaction between this magma and sialic material at depth, though there is evidence of the incorporation of silica during the emplacement and consolidation of the dyke. The unusually extensive metamorphism and permeation of the country rocks with potash is evidence of the high temperature of intrusion of the Newmains spessartite and also its richness in volatiles and alkalies. As in so many spessartite and kersantite dykes, the basic portions included in the Newmains dyke are probably fragments of marginal rock of an earlier consolidation, incorporated in a renewed upsurge of magma. The leucocratic variety of Newmains, however, appears to have segregated during the consolidation of the dyke, a feature to be expected in a high-temperature spessartite magma containing an excess of silica and richness in volatiles.

Considering the intimate association of the dykes of kersantite with the more numerous dykes of spessartite, it is tempting to attribute both groups to a common source. Although no chemical analysis of a Dalbeattie kersantite is available, the composition of similar kersantites indicates that the two rock-types are closely related, with the kersantites richer in potash and water but less rich in lime than the spessartites. Furthermore, it is interesting to note that H. G. Smith has recorded tridymite at the edge of quartz xenoliths in a kersantite near Sedbergh, suggesting that this group of minor intrusions might also have been intruded at a relatively high temperature.

The crystallisation of the kersantite dykes was complex. Original hornblende is now represented by pseudomorphs composed of a pale green amphibole and chlorite. Large flakes of biotite lie in an ill-defined, coarsely-intergrown base of un-twinned oligoclase which it has partially replaced. The numerous laths of tremolite scattered and clustered throughout the rocks are secondary in origin and probably developed as a result of the breakdown of primary hornblende. The more crystalline dykes are crowded with amygdales representing the infilling of gas bubbles by residual solutions, while the abnormal texture indicates an extensive post-consolidation re-crystallisation which was probably brought about by the passage of residual liquids or emanations from lower parts of such dykes. Although many kersantite dykes enclose xenocrysts and xenoliths of sialic material which undoubtedly played some part in their development, it is suggested that the kersantite dykes were developed from spessartite magma primarily by the upward passage of emanations through the consolidating dyke.

While emphasising the importance of the passage of emanations and gases along consolidating dykes, H. G. Smith is of the opinion that the frequent association of lamprophyres with granitic masses is entirely fortuitous, depending mainly on the existence of planes of weakness. However, while favouring the explanation of the spessartite magmas as a derivative of primary olivine-basalt magma, the writer considers there is a close petrogenetic relationship between the lamprophyres of this suite and the 'granitic' rocks. Many spessartites exhibit extensive alteration of their primary minerals which could have been effected by the passage of residual solutions rich in volatiles and alkalies. The kersantites, on the other hand, are regarded as the ultimate result of the re-crystallisation of consolidating spessartite dyke magmas through which solutions or emanations passed from below. It is not likely that such extensive re-crystallisation could have been effected by the residual solutions of a consolidating basic magma, but an external source of alkali-rich emanations is not difficult to find in this environment since the emplacement of some of the granodiorite masses was preceded by the permeation of the country rocks by sodium, potassium, silicon and aluminium. These emanations may have been more active at depth and if spessartite dyke fractures were available, the emanations might have found an easy passage along them. Consequently, reaction between high-temperature basaltic magma pockets and sialic material, prior to the development of the granodiorite magmas, and in some cases the later passage of emanations along the consolidating dykes, is regarded as the most likely mechanism for the development of the spessartite dykes and—in the latter case—the kersantite dykes of the Lower Old Red Sandstone suite of minor intrusions of the Dalbeattie area.

In conclusion, the author wishes to express his gratitude to Professor Alan Wood for reading and criticising the manuscript, and to Professor H. H. Read for his constant interest in the work. Thanks are also due to Mr. J. I. Platt, Dr. F. G. H. Blyth and Dr. S. W. Pitcher for the benefit of their consultation and advice, and to Dr. Sinha for carrying out the chemical analyses.

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On a Pillow-Lava at Cwm Idwal, Carnarvonshire, North Wales

by A. HUBERT COX

Received 21 November 1955

ABSTRACT: A spilite pillow-lava occupies the centre of a syncline in the Bala volcanic rocks above Llyn Idwal, which latter lies in a corrie on the west side of the Nant Ffrancon Pass. The pillow-lava forms the steep pitch in the Devil's Kitchen, well known to rock climbers in North Wales. Calcite dissolved from vesicles in the lava is probably an important factor in determining the richness of the mountain flora of Cwm Idwal.

IN VIEW OF the recent designation of Cwm Idwal as a Nature Reserve by the Nature Conservancy on the grounds of its scenic, geological and botanical interests, it appears appropriate to draw attention to the important factor of the occurrence of a spilite pillow-lava in the cliffs of Twll Du, the Devil's Kitchen.

Ramsay (1866) refers to the basin-like form of the strata in Twll Du, and to the 'rubbly felspathic vesicular conglomerate' (actually the pillow-lava) which '. . . forms the greater part of the broken ground in the upland valley above Twll Du'. Also he gives a very accurate section.

The structure of the cliffs above is synclinal, with the supposedly Bala rhyolitic rocks forming the main heights on either side of the Cwm. The cliffs culminate in Y Garn to the north-west, and Glyder Fawr to the south-east. The pillow-lava occupies lower ground in the centre of the syncline, as now exposed, between the two heights.

Later (1930) Dr. David Williams gave a detailed map of the area. He described the rock as an andesitic basalt, and quoted an analysis showing a silica content of 46.07 per cent.

During the discussion on this communication by Dr. Williams the present writer mentioned the existence of a pillow-lava in the upper part of the Twll Du cleft (Williams, 1930, p. 231).

It has been noted in other areas, e.g. the slopes below Llyn-y-Gader, on the north face of Cader Idris, that the surfaces beneath the outcrops of pillow-lavas yield an unusually rich botanical assemblage, due, presumably, to the presence of calcite washed from the vesicles of the pillow-lavas (E. P. Evans, 1932, p. 35).

Similarly, the richness of the flora on the eastern slopes of Cwm Idwal is due, at least in part, to lime derived from the pillow-lava of the Devil's Kitchen.

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The Heavy Mineral Suites of the Lower Greensand of the Western Weald

by G. V. WOOD

Received 20 April 1955

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ABSTRACT: The heavy mineral suites of the Lower Greensand have been examined quantitatively and the suites of each of the lithological divisions compared.

The Folkestone Sands contain residues much richer in kyanite than the suites yielded by the Atherfield Clay, the Hythe Beds and the Sandgate Beds. It is suggested that this richness may be used as a confirmatory test in field mapping.

The Nutfield Fuller's Earth suite is abnormal in containing a high proportion of minerals to which an authigenic origin may be attributed.

The bulk of the material is believed to have come from the London Platform, but Armorica must have contributed also—particularly to the Folkestone Sands.

1. INTRODUCTION

(a) **Previous work.** Publications dealing with the heavy minerals of the Lower Greensand of the Western Weald are few. In 1916 Davies listed assemblages from the Reigate area. The minerals were classified as extremely abundant, abundant and scarce. No indication was given of any variation in heavy mineral content between the different subdivisions. In 1930 Hayward described in greater detail suites from the Leith Hill neighbourhood. He noted (p. 26) that tourmaline, while being abundant in the Hythe Beds, was only frequent in the Folkestone Beds and that muscovite, though rare in the Hythe Beds, was frequent in the Folkestone Beds. In 1937 Newton, in his account of the Fuller's Earth beds of Nutfield, gave a full description of their heavy minerals. He regarded certain minerals as probably authigenic, and for quantitative purposes only used a five-fold division ranging from abundant to rare.

As regards provenance, Groves (1931) stated that he had been unable to find any characteristic Dartmoor minerals in the Lower Greensand of the Weald. Hayward was not so dogmatic, suggesting (1932, p. 32) that Dartmoor, Armorica and the crystalline and metamorphic rocks of the London Platform might have contributed. Newton concluded that the distinctive suite with which he had dealt could not have been derived from pre-existing sediments and little contribution could have come from igneous or metamorphic rocks to the north, west or south, so the London Platform was important as a probable source (1937, p. 192).

It was hoped that a quantitative investigation of the heavy minerals suites of the various subdivisions of the Lower Greensand of the Western Weald (i.e. west of Godstone and Pulborough) would show whether there was any horizontal and vertical variation. This might provide evidence as to the source and, perhaps, the conditions of deposition of the beds, whilst any vertical variation might be of value in the mapping of areas of structural difficulty. In these almost unfossiliferous beds, with their rapid changes in lithology, it is often difficult to assign small exposures to their correct horizons. Any additional means by which this could be done might be of value to other workers.

(b) **The variation in lithology of the Lower Greensand of the Western Weald.** The Lower Greensand of the Weald is subdivided as follows:

4. Folkestone Sands
3. Sandgate Beds
2. Hythe Beds
1. Atherfield Clay

In the type-area of East Kent these divisions have some palaeontological significance, but farther west they have to be distinguished almost entirely in terms of their lithologies.

The Atherfield Clay is exposed very infrequently, usually being hidden by the thick downwash from the scarp formed by the Hythe Beds. When seen it is usually a silty clay, reddish-brown or grey in colour.

The Hythe Beds from Godstone to the River Arun are of the arenaceous facies, forming a monotonous series of limonitic sands and sandstones with developments of cherty sandstones and, very locally, true cherts. To the east of Pulborough they change into the calcareous facies of fine-grained sands and sandy limestones.

The Sandgate Beds are much more variable, and a considerable number of local units have been recognised (Fig. 1).

Normally the Folkestone Sands consist of clean-washed, reddish, yellow or white sands. In the extreme south-west corner of the Weald, round Petersfield, thin seams of pipe-clay are conspicuously developed, whilst on

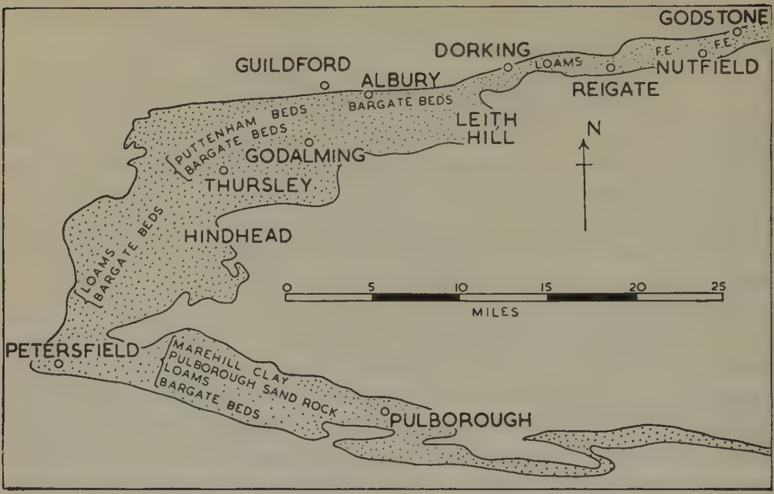


Fig. 1. Lateral variation of the Sandgate Beds in the Western Weald
Outcrop of the Lower Greensand stippled
F.E.: Fuller's Earth developed

the north crop, Gossling has succeeded in tracing a distinctive clay-silt horizon from Dorking to Westerham (Kirkaldy, 1947).

2. SAMPLING AND LABORATORY PROCEDURE

Sampling was concentrated in the four areas Reigate, Albury, Thursley and Pulborough (see Fig. 1), where there are numerous exposures in the different subdivisions. Whenever possible, intermediate sampling was carried out at intervals of not more than two miles along the strike. A particularly useful series (Fig. 2) was obtained from a water supply trench at Pulborough (the Park Mound Trench) extending from Hardham Mill (51/034178) to just west of Pulborough Station (51/042188). This trench exposed the greater part of the Folkestone Sands and the whole of the Sandgate Beds above the Bargate Beds.

Except for the almost completely white portions of the Folkestone Sands, the grains were usually so heavily stained with limonite that preliminary treatment was necessary. Each sample was boiled in N/10 hydrochloric acid. For the more limonitic sands, boiling for thirty minutes was found to be necessary. It is realised that the virtual absence of apatite is possibly due to this treatment.

The heavy mineral residues were separated in bromoform and mounted in Canada balsam. No attempt was made to concentrate the heavy grains by panning, for Ewing (1931) has shown that the proportion of relatively light minerals, such as kyanite, is reduced by preliminary panning.

The methods of counting and measuring which were adopted differ somewhat from those used by other workers. A Dollar Integrating Micrometer Stage was used. A square grid was placed in the focal plane of the microscope objective so that both grid and slide were in focus together. In this way, with a quarter-inch objective, grain size could be measured to within 4 μ (0.004 mm.). With grain sizes normally ranging between 70 μ and 200 μ this was considered to afford a sufficient accuracy. Each slide was traversed systematically until, if possible, a thousand grains had been counted, although for the coarser samples—especially those from the Folkestone Sands—the number of grains had to be less than this. The 'zircon size index' (Allen, 1949, pp. 261–2) was determined, to give an indication of the size of the suite. The mineralogical characters of each mineral were noted.

3. THE HEAVY MINERAL SUITES

The following twenty-six minerals occurred in the slides examined.

Minerals marked '(a)' may be of authigenic origin; those marked '(d)' are clearly of detrital origin.

Galena	(a)	Amphibole	(d)
Garnet	(d)	Biotite	(d)
Magnetite	(d)	Epidote: very rare	(d)
Pyrite	(a)	Monazite: very rare	(d)
Sphalerite	(a)	Muscovite	(d)
Spinel, green	(d)	Sphene	(a)
Anatate	(a) & (d)	Kyanite	(d)
Rutile	(a) & (d)	Apatite	(a)
Zircon	(d)	Ilmenite	(d)
Andalusite (?): extremely rare	(d)	Tourmaline	(d)
Barytes	(a)	Glauconite	(a) & (d)
Sillimanite	(d)	Leucoxene	(a)
Staurolite	(d)	Limonite	(a)

Seven minerals, galena, pyrite, sphalerite, barytes, biotite, sphene and apatite, were restricted to the Fuller's Earth beds of Nutfield.

The slides prepared for this investigation have been deposited in the Geology Department, Queen Mary College, University of London.

(a) **Vertical and horizontal variation.** The suite from the Fuller's Earth beds is clearly abnormal and will be considered later (p. 132). In Table I is given a selection of typical counts from the remaining subdivisions. The localities for each subdivision are arranged in a counter-clockwise order round the outcrop.

The essential homogeneity, both vertically and horizontally, of the suites yielded by the Atherfield Clay, the Hythe Beds and the Sandgate

Beds is clearly shown. On the other hand, all samples from the Folkestone Sands show a marked increase in the relative proportion of kyanite and a decrease in the amount of zircon. The variations in the proportions of the

TABLE I

Locality	Grid ref.	1	2	3	4	5	6	7
Atherfield Clay								
1 Reigate	51/265492	2	7	6	1	87	—	47
2 Brook	41/932378	tr.	5	2	1	92	—	59
Hythe Beds (lower part)								
3 Nutfield	51/306501	5	15	13	2	64	—	109
4 Albury	51/022481	4	15	8	2	71	C.G., tr.	112
5 Hambledon	41/967386	2	10	5	1	82	Y.A. & C.G., tr.	84
6 Witley	41/952385	5	15	4	1	73	C.G., 1%	97
7 Brook	41/932378	tr.	8	3	1	89	M., tr.	65
8 Pulborough	51/062199	tr.	10	6	1	81	C.G., 2%	65
Hythe Beds (upper part)								
9 Godstone	51/359507	5	12	11	2	70	Amp. & E., tr.	92
10 Reigate	51/247496	2	9	8	1	81	—	89
11 Albury	51/048474	3	11	9	2	73	Amp. & E., tr. C.G. 1%	89
12 Godalming	41/969445	3	15	8	2	72	C.G., tr.	90
13 Hambledon	41/967400	1	8	7	1	83	—	97
14 Rogate	41/803256	3	14	8	2	76	Amp., tr.	112
15 Thakeham	51/102165	tr.	7	9	1	81	C.G., 1%, B.A., tr.	80
Bargate Beds								
16 Albury	51/045482	3	11	7	1	76	C.G. & Y.A., tr.	92
17 Thursley	41/915395	2	9	3	1	85	C.G., tr.	74
18 Churt	41/865382	1	6	1	2	90	—	93
19 Woolbeding	41/875230	1	12	7	1	78	Amp., 1%	83
Puttenham Beds								
20 Thursley (lower)	41/916397	3	12	5	1	79	—	80
21 Thursley (upper)	41/916397)	13	15	6	1	65	—	104
22 Thursley	41/896398	1	10	2	2	85	—	79
Loams of Sandgate Beds of Sussex								
23 Liss	41/807291	2	12	7	2	77	—	76
24 Fittleworth	51/005194	1	12	8	2	77	—	75
25 Pulborough	51/042188	tr.	10	8	2	80	Y.G., tr.	77
26 Thakeham	51/102165	tr.	7	4	1	88	C.G., tr.	77
Folkestone Sands								
27 Godstone (Silt Band)	51/356516	12	16	5	2	65	—	62
28 Nutfield	51/295505	18	7	3	2	70	—	96
29 Reigate	51/244516	24	8	4	1	63	—	91
30 Albury	51/022483	25	9	4	1	61	—	100
31 Farnham	41/855474	36	12	3	4	45	—	127
32 Petersfield	41/784230	34	17	6	1	42	—	104
33 Petersfield	51/034178	35	14	6	2	43	—	131

other minerals seem to be random. The counts of suites from the Park Mound Trench (which are not included in Table I) show a sharp mineralogical break at the base of the Folkestone Sands (Fig. 2).

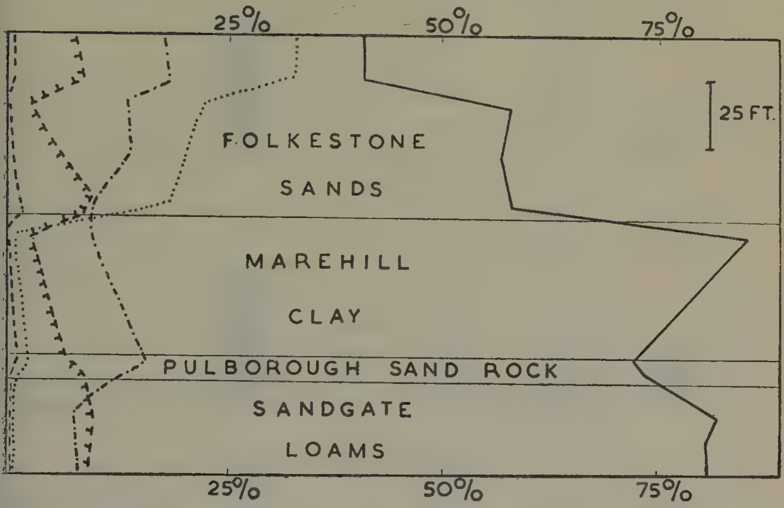


Fig. 2. Percentage variation of the commoner heavy minerals in the Park Mound Trench, Pulborough, Sussex

Key:

—— Zircon ------ Staurolite -·-·- Rutile

.... Kyanite ⊤⊤⊤⊤⊤ Tourmaline

Samples 20 and 21 from the Puttenham Beds (see Table I) deserve special comment. Rogers & Richardson recognised two local units in the Puttenham Beds of the Thursley area and suggested (1947, p. 263) that the upper unit was transitional between the lower beds and the Folkestone Sands. It is interesting to note that the same indication is given by the heavy mineral suites. Unfortunately the author's departure to Malaya prevented him from following up this and other suggestive points (e.g. p. 133).

Key: Table I

Column
1. Percentage of Kyanite.
2. Percentage of Staurolite.
3. Percentage of Tourmaline.
4. Percentage of Rutile.
5. Percentage of Zircon.

Column
6. Other minerals present in significant quantity:
   tr.: trace
   B.A.: Blue Anatase
   E.: Epidote
   Y.G.: Yellow Garnet
   Amp.: Amphibole
   Y.A.: Yellow Anatase
   C.G.: Colourless Garnet
   M.: Monazite
7. Zircon Size Index in μ.

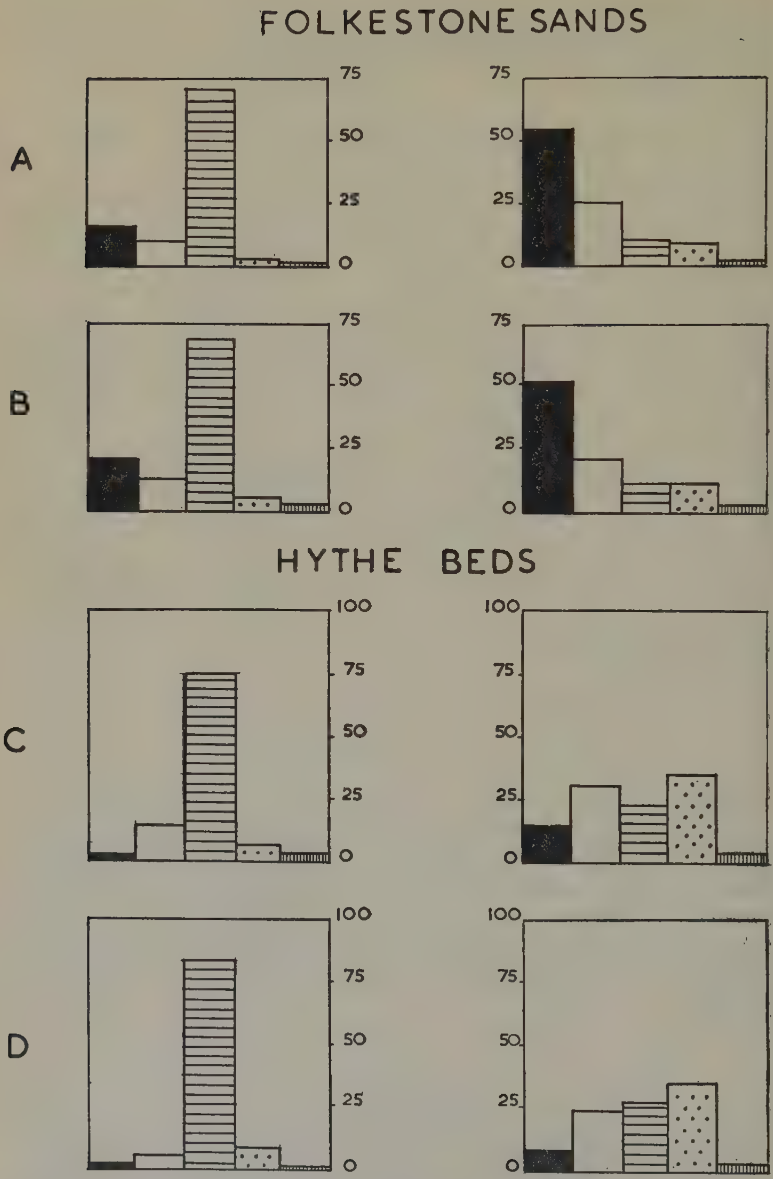


Fig. 3. Histograms illustrating variation in heavy mineral percentages with grain size

For explanation see facing page

(b) **The possible effect of grading.** As Allen (1949) and others have shown, the composition of mineral suites is determined both by the material supplied and by the conditions under which they were deposited. Variation in the proportion of different minerals may be due to the selective action of bottom currents, for example.

In certain areas the Lower Greensand is notorious for showing rapid variation in its grading (e.g. Rogers & Richardson, 1947). During collecting in each subdivision care was taken to sample as wide a range of grain size as possible. The range in zircon size-index in Table I indicates this, although the yield of heavy minerals from the coarser sands was usually too small for a significant number to be counted.

The major variation between the suites of the Atherfield Clay and Sandgate Beds on the one hand, and of the Folkestone Sands on the other, is clearly not just a function of grading. Compare, for example, samples 2, 8 and 27 of Table I, and also samples 6, 13, 18 and 28. The first group was separated from silty sands; the second from fine sands. In Fig. 3 are shown the results of sieving ill-graded samples from the Hythe Beds and the Folkestone Sands into silt grade (less than 0.1 mm. diameter), fine sand (0.1–0.25 mm.) and medium sand (greater than 0.25 mm. in diameter), and then counting the heavy minerals present in each sieved sample. The grains from the coarsest fraction were too few to be plotted. Both grades of samples from the Folkestone Sands show a consistent difference from those obtained from the Hythe Beds.

It is not suggested that grading has no effect. In Fig. 4 are shown the results of plotting the frequency of various minerals against the zircon size-index. Whilst the percentage of zircon increases in the sands of finest grade, and kyanite shows the converse change, these changes are overshadowed by the increase in the proportions of kyanite in the Folkestone Sands, whatever their grading, as compared with its occurrence in the underlying beds.

Left-hand column <0.1 mm. Right-hand column >0.1 mm. <0.25 mm.

Key to histograms:

Black	Kyanite
White	Staurolite
Horizontal Lines	Zircon
Dotted	Tourmaline
Vertical Lines	Rutile

Localities:

A. Leasers Barn, Wotton, Surrey (51/112482)
B. Thursley Common, Surrey (41/902413)
C. Cockshot Hill, Reigate (51/257494)
D. Road Cutting, Brook, Surrey (41/930386)

(c) **The Nutfield Fuller's Earth Series.** The abnormal suite of heavy minerals in these beds calls for special mention. The beds, up to seventy feet in thickness, are lenticular in occurrence, being restricted to about six miles of outcrop on either side of Nutfield.

In the Cockley Pit, Nutfield (51/296505), the following general succession was exposed in 1954:

	ft.	in.
8. Brownish-buff loam—superficial layer	6	0
7. Current-bedded pebbly sand	12	0
6. Glauconitic loamy sand, with calcareous doggers at base ...	6	0
5. Loamy sand, 'buff'	10	0
4. Massive calcareous sandstone, 'buffstone'	8	0
3. Thin sandy seam of Fuller's Earth...		6
2. Massive calcareous sandstone, 'buffstone'	12	0
1. Main Fuller's Earth	14	0

As stated by Newton (1937), the seams of Fuller's Earth yield a different suite of minerals from those of the other beds. In Table II are shown the results of percentage counts of samples from this pit.

TABLE II

	K.	St.	T.	R.	Z.	Ba.	Ap.	Sp.	Bi.
Bed 7	18	7	3	2	70	—	—	—	—
Bed 6	3	14	7	1	75	—	—	—	—
Bed 3	—	1	tr.	—	8	28	32	37	3
Bed 2	1	2	1	tr.	36	6	26	25	3
Bed 1 (top) ...	—	—	—	2	3	56	15	17	5

Key: K.: Kyanite
St.: Staurolite
T.: Tourmaline
R.: Rutile
Z.: Zircon
Ba.: Barytes
Ap.: Apatite
Sp.: Sphene
Bi.: Biotite

As Bed 7 has been regarded by Dines & Edmunds (1932, p. 69) as the base of the Folkestone Beds, it is interesting to note that there is a mineralogical break between Bed 6 and Bed 7. The suite obtained from the 'buff' of Bed 2 is significant, for it is a mixture of the usual detrital minerals and of the assemblage, believed to be authigenic, which predominate in the true Fuller's Earths. If these special minerals are ignored, the suite of the 'buff' is identical with that of the normal Sandgate Beds.

The exact conditions of deposition of the Fuller's Earth are uncertain, but probably it was in large part a chemical precipitate as suggested by Cox (1918). The mineralogical evidence suggests that the Fuller's Earth Series is a rhythmic deposit laid down in a sheltered area, as indicated by Newton. There were periodic influxes of arenaceous material. These became more dominant in the upper part of the succession until Bed 6

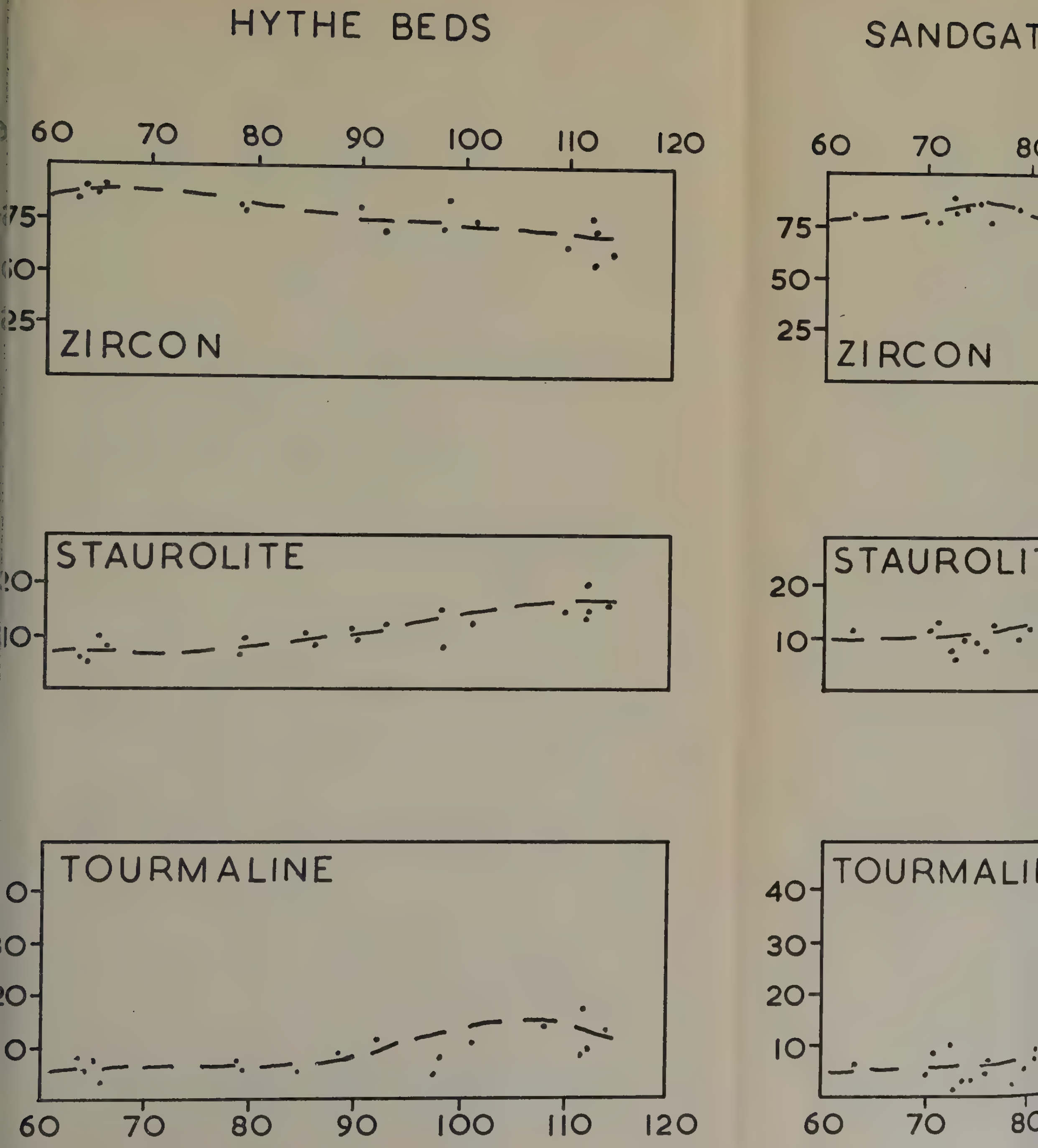
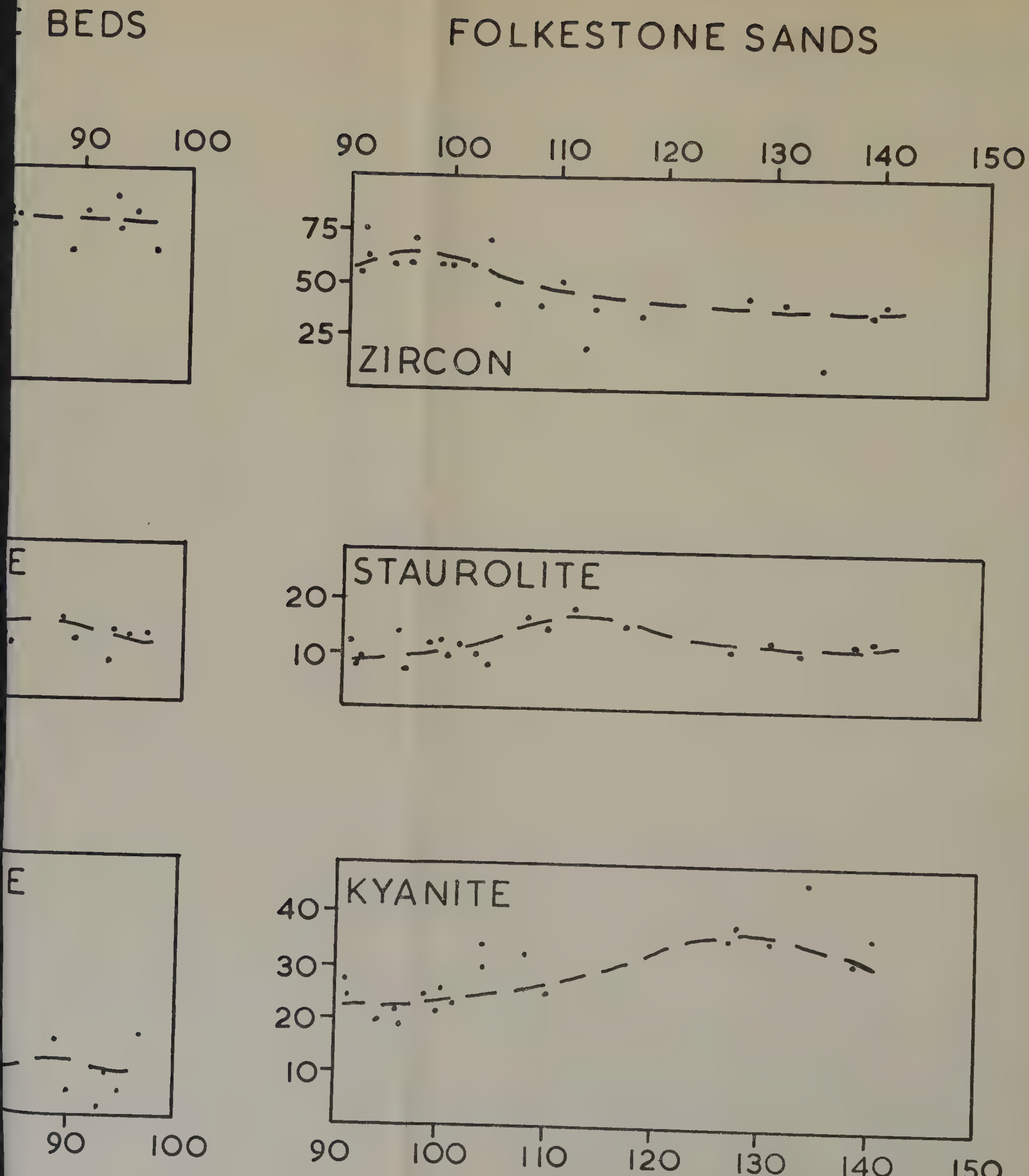


Fig. 4. Percentages (ordinates) of the commoner h



y minerals plotted against zircon size-index represents a complete return to the normal conditions of deposition of the Sandgate Beds.

One further point arising from the Fuller's Earth Series concerns the origin and distribution of glauconite in the Lower Greensand. This mineral has not been included in the counts, for its specific gravity is near 2.9 and therefore only its heavier grains sink in bromoform. When collecting and separating samples it was noticed that, except in the Folkestone Sands containing little or no glauconite, there seemed to be an inverse relation between the abundance of glauconite and that of limonite. American workers on the genesis of glauconite (e.g. Galliher, 1935) claim that glauconite occurs as the end-product of the decomposition of biotite. The only horizon in the Lower Greensand known to contain detrital biotite is the Nutfield Fuller's Earth Series, which is almost free of glauconite and limonite. The author has found a small amount of glauconite in the 'buff', but he has been unable to confirm Newton's record (1937, p. 182) of glauconite in the true Fuller's Earth. As the decomposition of glauconite to limonite is well known it is suggested therefore that in the Lower Greensand these minerals form a three-fold decomposition series, viz.:

$$\text{biotite} \longrightarrow \text{glauconite} \longrightarrow \text{limonite}$$

It is probable that the decomposition of the glauconite is largely controlled by the grade of the sediment. The larger the pore-space, the greater the ease of breakdown of glauconite.

4. DERIVATION

The basin in which the Lower Cretaceous beds were deposited was bounded on the north and east by the London Platform and on the west by uplands including the crystalline rocks of Armorica and Dartmoor. Allen has shown that the great bulk of the material forming the Hastings Beds of the Wealden came from the London Platform. He has traced the position of two rivers: one flowing from the Dover neighbourhood to deposit the Top Ashdown Pebble Bed, and the other from the London region, laying down the Top Ashdown and the Lower Tunbridge Wells Pebble Beds of the East Grinstead–Haywards Heath neighbourhoods (Allen, 1954, fig. 1, p. 501), i.e. well to the east of the area dealt with in this communication. But he has also suggested (Allen, 1949, fig. 23, p. 305) that there was some contribution, particularly of kyanite, staurolite and sillimanite, from Armorica. Groves (1931) and Kirkaldy (1947b) have shown that a river from the Dartmoor region contributed substantially to the Wealden Beds of Dorset and traces of the characteristic Dartmoor minerals have been found towards the top of the Weald Clay of Surrey (Groves, 1931, p. 70). Armorican, and not Dartmoor, detritus occurs in the

Wealden Beds of the Isle of Wight (Groves, p. 71; Allen 1949, p. 300) (Fig. 5).

But when the transgressing Aptian sea spread across the delta plains of the Wealden, this clear-cut picture became blurred. Longshore drift and current action swept the detritus to and fro. As shown elsewhere in this paper (p. 125), previous workers on the heavy minerals of the Lower Greensand have been unable to reach very definite conclusions as to their derivation. In certain areas, at least, clearer evidence has been given by the coarser constituents of the beds. Ever since the work of Meÿer (1868) and Chapman (1894) it has been realised that the derived ooliths and fossils of the Bargate Beds must have come from the London Platform, and Arkell (1939) has stressed that the derived Oxfordian ammonites could not have travelled far. Wells & Gossling (1947), in studying the pebble beds of the extreme north-east part of the area dealt with here, have pointed out that there is a difference between the suites found in the Hythe Beds and the Folkestone Sands. The former consists of quartz, chert, phosphate and ferruginous pebbles, while the latter consists of quartz, chert, quartzite, sandstone, siltstone and ironstone, and 'phosphate is virtually suppressed' (ibid., p. 201). Furthermore, in the Folkestone Sands pebbles of acid igneous rocks occur in very small quantity. As regards derivation, they believed that the cherts, phosphates and ironstones could all have come from the London Platform, but south-west England is suggested as a source for the very occasional pebbles of killas and tough siltstone containing tourmaline and zoned zircons. In this connection it is interesting to note that Allen has not found any tourmalinised pebbles in the Hastings Beds (1954, p. 505). Certain quartzites, and the acid lavas, were referred to an Armorican source by Wells & Gossling, though this may need reconsideration, now that Allen has claimed the very infrequent acid lavas found in the Wealden pebble beds strongly resemble varieties described from the Old Red Sandstone conglomerates of the Bristol district. Borings have proved the presence of conglomerates in the Old Red Sandstone of the London Platform. The study of these pebble beds has shown, firstly, that there is a difference between the suites yielded by the Hythe Beds and the Folkestone Sands and, secondly, that the different varieties of pebbles, which may not have come from the London Platform, have been found only in the Folkestone Sands.

The evidence of the heavy minerals is clearly in agreement with this. The suite of the Folkestone Sands is characterised not only by this persistent increase in the proportion of kyanite, as compared with the suites of the underlying beds, but also by significant features shown by the staurolites. Those of the Hythe Beds and the Sandgate Beds are pale yellowish in colour, but in the Folkestone Sands these are dominated by larger, more angular reddish-brown grains.

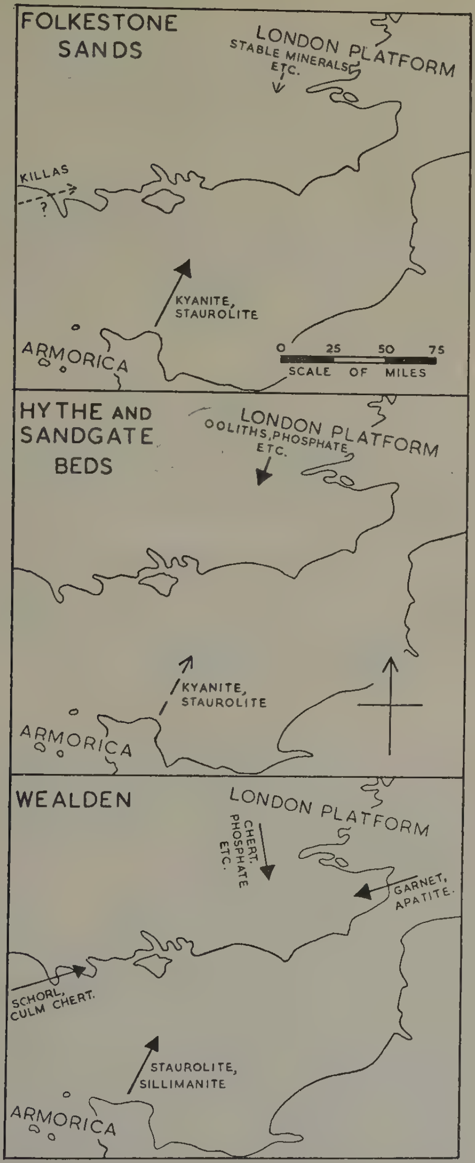


Fig. 5. Possible sources for the detritus of the Lower Greensand and the Wealden Beds. Relative importance is indicated by the size and strength of the arrow in each case. The two upper maps relate only to the Lower Greensand of the Western Weald

Throughout the Lower Greensand the bulk of the residues could very well have been derived from the Mesozoic and Palaeozoic rocks of the London Platform, but there must also have been some contribution from Armorica. The varieties of kyanite resemble those described by Lacroix (1893) from the granites of Finisterre and Morbihan, whilst several of the types of tourmaline are similar to those which Berthois (1929) found associated with the Brittany granites. This Armorican contribution must have increased considerably at the beginning of the deposition of the Folkestone Sands. Characteristic Dartmoor minerals have not been detected with certainty during this investigation, but the rare tourmalinised pebbles found by Wells & Gossling suggest spasmodic influxes from this source.

ACKNOWLEDGMENTS

Sincere thanks are due to Dr. J. F. Kirkaldy, not only for suggesting this field of study, but also for his continual help and guidance, and help in seeing this communication through the press. Many friends at Queen Mary College have helped with suggestions about collecting localities; particularly Mr. R. G. S. Westbury.

Also thanks are due to the West Sussex Water Board, and to Mr. A. Ridout, for access to the Park Mound Trench, and to the Fuller's Earth Union Ltd., for permission to examine Cockley Pit, Nutfield. A grant from the Central Research Fund of the University of London, which has helped to defray the cost of travelling, is gratefully acknowledged.

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The Mineralogy of Some Lower Greensand Borehole Samples in Kent

by G. A. WORRALL

Received 25 September 1955

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2. Mineralogical Analyses ... 138
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ABSTRACT: Analyses are given of the heavy minerals and calcium carbonate content of samples from three boreholes in Kentish Lower Greensand. The results give some indication of the underground extent of the Hythe Beds and certain mineralogical changes which have occurred in their outcrops after deposition. These changes are explained as having begun with the removal of the impervious Gault cover which resulted in the leaching of the upper beds of the Lower Greensand to cause mineralogical alterations including the solution of calcium carbonate, its precipitation in the Hythe Beds, and the consequent formation of Rag and Hassock.

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1. INTRODUCTION

FOLLOWING previous work on the outcrops of the Lower Greensand in East Kent (Worrall, 1954), further analyses have been made of borehole samples kindly provided by H.M. Geological Survey, with a view to determining whether the Hythe Beds do in fact thin out completely immediately they pass under the Gault, or whether they merely change their facies from Rag and Hassock to glauconitic sand.

2. MINERALOGICAL ANALYSES

Nine samples were available, out of which only five were sufficiently large for the extraction of heavy minerals. The samples were derived from the boreholes at St. Margaret's Bay, Ebbesfleet and Fredville. Those from St. Margaret's Bay were of particular interest as being rich in ferruginised casts of foraminifera.

The analyses listed in Table I indicate that, although there is some general resemblance to the minerals of the outcropping beds as a whole, particularly in the proportions and varietal features of zircon, the differences obtaining between the outcropping beds are not apparent in the borehole samples. In the outcrops the Hythe Beds are distinct in possessing a higher content of tourmaline (especially a deep blue variety), garnet and

TABLE I: Approximate Percentages of Non-opaque Minerals in Borehole Samples

MINERALS LOCALITIES	Zircon, clear	Zircon, purple	Rutile, red	Rutile, yellow	Tourmaline, dusky	Tourmaline, blue	Garnet, colourless	Garnet, pink	Garnet, green	Kyanite	Sillimanite	Chlorite	Topaz	Staurolite	Monazite	Hornblende	Epidote
St. Margaret's Bay *Folkestone Beds*	70	8	1	–	4	–	2	–	–	2	2	1	–	6	1	–	–
St. Margaret's Bay *Sandgate Beds*	60	1	1	–	10	<1	2	–	–	2	–	10	<1	8	1	–	–
Ebbesfleet *Folkestone Beds*	60	1	1	6	10	–	2	–	4	<1	–	10	<1	<1	–	–	–
Ebbesfleet *Sandgate Beds*	75	1	–	6	6	–	1	–	–	1	<1	6	1	–	–	2	–
Fredville *? Sandgate Beds*	65	1	2	5	6	–	<1	<1	–	4	1	<1	–	4	–	1	1

kyanite than the Sandgate or Folkestone Beds, and chlorite and chert are restricted to the Hythe Beds. In the borehole samples these differences are not seen, except for the presence of a single blue tourmaline in the 'Sandgate Beds'[1] of St. Margaret's Bay. As, however, this is a '*rare to very rare*' mineral, as seen in the larger outcrop samples of Hythe Beds, and absent from the others, it is indicative of the presence of the Hythe Beds underground. Of the other minerals, garnet is absent in all but one sample; kyanite occurs only rarely in all samples, and chert is absent. On the other hand, chlorite occurs in all samples; generally more frequently than in the outcropping beds.

An explanation of some of these differences may be found in considering the possible changes which may have occurred as a result of the uncovering of the Lower Greensand Beds. The Folkestone and Sandgate Beds, being sufficiently permeable to permit leaching, may have lost their chlorite by solution, while the Hythe Beds retained their chlorite because the groundwater has been held up by the underlying impermeable Atherfield Clay and Weald Clay. Probably the chert fragments in the Rag and Hassock were bits of broken shell, originally, since they occur in the borehole samples (see below). Garnet is, of course, sporadic in its occurrence, while the differences in the content of kyanite cannot be explained. Further samples would be needed before more could be said in these connections.

3. CARBONATE ANALYSES

Results of analyses, expressed as calcium carbonate, using a Collins Calcimeter, are as follows:

BOREHOLES	SAMPLE REFERENCE	DEPTH	CALCIUM CARBONATE %
St. Margaret's Bay:	'Folkestone Beds'	851 ft.	1.4
	'Sandgate Beds'	901–905 ft.	0.5
Ebbesfleet: PL3906	'Folkestone Beds'	1034 ft. 2 in.–	16.3
PL3906	'Folkestone Beds'	1035 ft.	1.3
PL3900	'Sandgate Beds'	1041 ft.	8.3
PL3895	'Sandgate Beds'	1037–8 ft.	5.2
Fredville: L2721	'?Sandgate Beds'	969 ft.	0.0
Oxney K551	'Sandgate Beds'	836–855 ft. 6 in.	6.3
East Kent Colliery: O2121	'Sandgate Beds'	311–327 ft	0.0
Harmonsole: RE297	'Sandgate Beds'	767 ft.	6.5

These values give an average content of calcium carbonate of 4.6 per cent. The source of the latter appears to be comminuted shells in most cases, but these are absent in the outcrops except in the Rag and Hassock, where they are silicified. It is suggested that, with the removal of the protective cap of the Gault, the shell fragments in the Folkestone and Sandgate

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[1] All names and reference numbers are those of H.M. Geological Survey.

Beds were dissolved by percolating rainwater, to be re-deposited rhythmically in the Hythe Beds to form the Rag and Hassock. This is in keeping with the 'superficial effect' suggested by Wooldridge (see Kirkaldy, 1937, p. 123). The shelly deposits are deposited irregularly, as is to be expected, and no doubt further analyses on larger samples would show whether formerly there was sufficient lime in the Sandgate and Folkestone Beds to account for the amount now present in the Rag and Hassock. If there was sufficient at that time, then it would be expected that underground samples of Lower Greensand, lying immediately north of the outcrop in the Western Weald where the Hythe Beds are non-calcareous, would be non-calcareous also. The few feet of supposed Neocomian in the Richmond borehole, described by Judd (1884) as resembling certain varieties of Kentish Ragstone, would appear to conflict with this suggestion. These samples have been examined by the writer who found that though there was some similarity to Ragstone in hand specimen, in thin section they were very different, since they consist largely of organic remains with practically no quartz or glauconite. They may be connected with the Bargate Beds, as Chapman suggested (1894), but not with the Ragstone.

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Construction of Block Diagrams to Scale in Orthographic Projection

by D. B. McINTYRE and L. E. WEISS

Received 22 July 1954

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ABSTRACT: This paper describes a simple method for constructing block diagrams to scale in orthographic projection by the use of an orthographic net. The procedure is illustrated by reference to an actual example of considerable complexity. An alternative construction, using a stereographic net, is also given.

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1. INTRODUCTION

BLOCK DIAGRAMS can be used effectively as illustrations of rock structures (e.g. Lobeck, 1924), and Goguel (1952, pp. 115–16) has described a simple construction for the representation of topographic relief in the form of such diagrams. It is the case, however, that block diagrams have seldom been used to show the structure of a mass of rock accurately and to scale. The main reason for this is that the scale of a block diagram varies in different directions and for each angle of sight; in point-perspective projections it is not constant even in any one direction. Accurate representation of distances and angles has been supposed to be difficult therefore (Billings, 1942, pp. 85–6).

The special case of an orthographic projection of a rectangular block, viewed from such an angle that all edges are foreshortened equally, has been discussed by Johnston & Nolan (1937), and isometric graph-paper to facilitate this construction is available commercially (e.g. from H. K. Lewis, 136 Gower Street, London, W.C.1, England). It is the purpose of this paper to show how a block diagram may be constructed in orthographic projection without difficulty, and for any required angle of sight, from given structural data, so that scales along every direction are known, and all faces of the block give accurate representations of the traces of the structures shown on them.

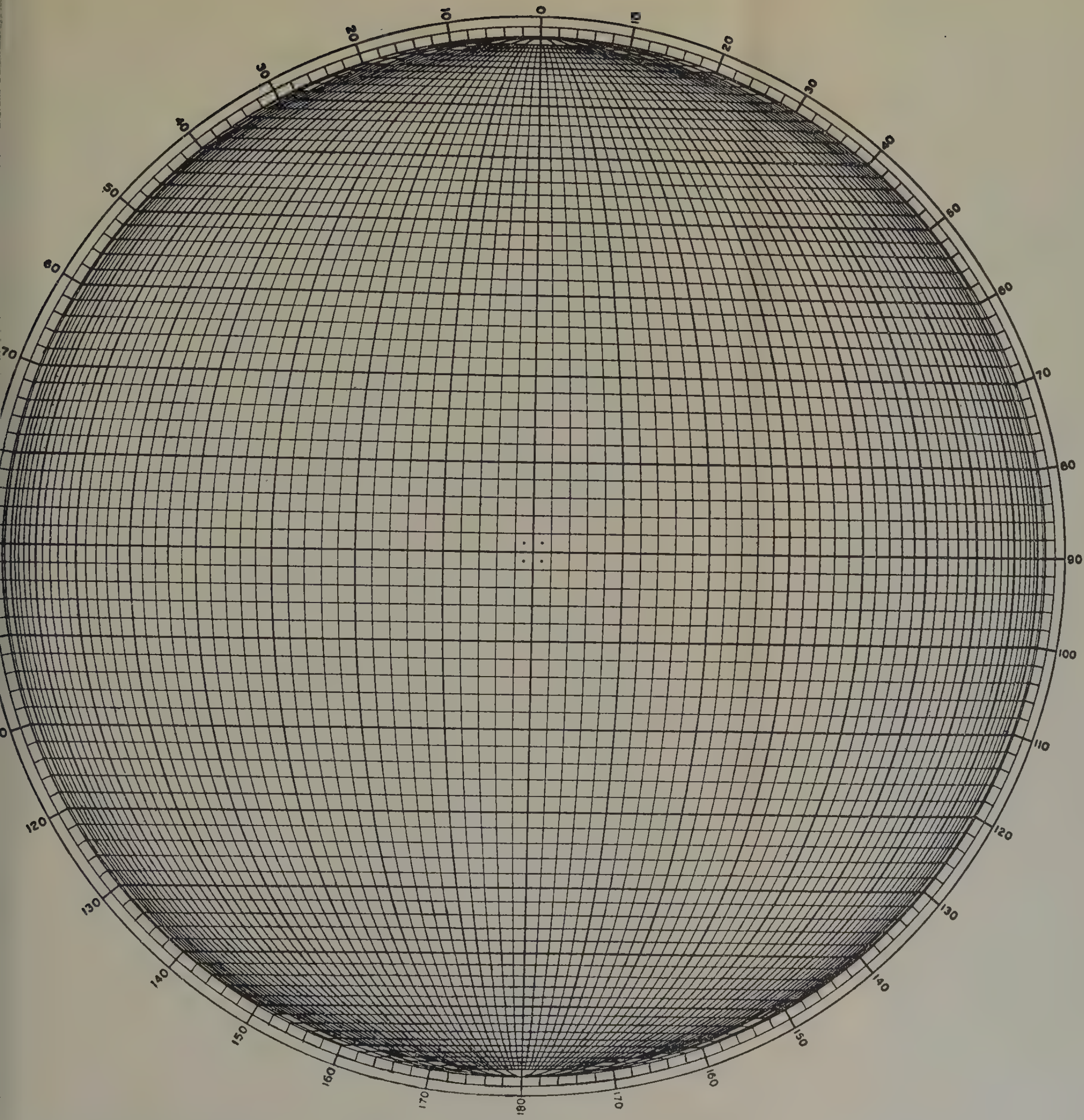

Fig. 1. Orthographic net, based on Wright (1911, pl. 4), by permission of the Trustees, Carnegie Institute of Washington, U.S.A.

[*To face p.* 142

2. ORTHOGRAPHIC PROJECTION AND THE ORTHOGRAPHIC NET

A projection is *orthographic* if the lines of projection are mutually parallel and normal to the plane of projection. The perspective of the projection is such that the vanishing-point is at infinity, and all lines which are parallel on an object remain parallel upon its projection.

An *orthographic net* can be prepared in the same manner as a stereographic net (see Hutchinson, 1908, pp. 105–12; Wright, 1916) by projecting the lines of latitude and longitude of a hemisphere on to a plane containing the polar axis. The circles of latitude project as straight lines and the meridians of longitude project as ellipses. The orthographic net compares closely with the view of a suitably inscribed and oriented sphere obtained at a distance. It is the Man-in-the-Moon's view of the Earth and our view of the Moon. Because of this the orthographic net has been used for mapping planetary bodies; for instance orthographic nets (sun-discs) for determining the latitude and longitude of sun spots were formerly published for the Stonyhurst Observatory by Casella and Co., London. Another interesting application of the projection is in the calibration of sun-dials. F. E. Wright (1907, 1911 and 1913) has pointed out that interference

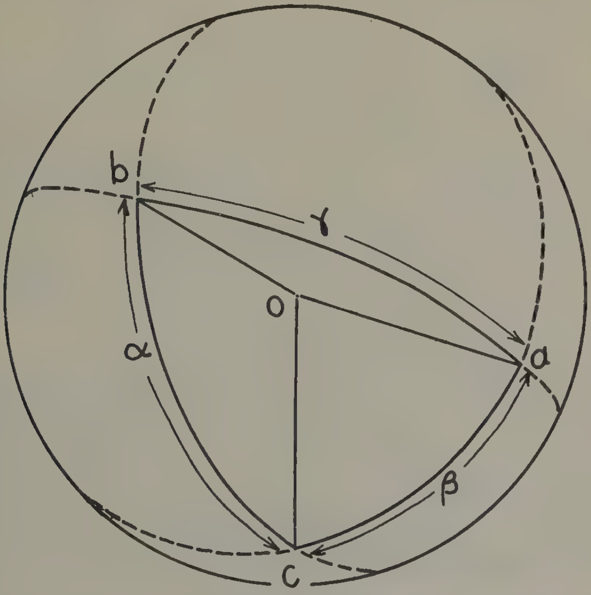

Fig. 2. Orthographic projection of three axes, *a*, *b*, and *c*, intersecting at O. The angles α, β, and γ define their relative orientations

figures are orthographic projections of interference phenomena in space, and has published nets of 10 cm. (1907) and 20 cm. (1911) diameter. A reduction of Wright's 20 cm. net appears in Fig. 1.

Hilton (1917, 1917a) has published methods of rotation (without the use of nets) on orthographic, gnomonic and stereographic projections and Wright (1932) has also contributed to this subject. The equations for great and small circles in these three projections, as well as in two related projections, have been given by Wright (1929. For further particulars, see also Hilton, 1903, 1904, 1917, 1917a).

Hilton (1904, 1917a; see Barker, 1922, p. 48, footnote) has shown how to determine directions of crystal edges in orthographic projection from gnomonic and stereographic nets. Also he was the first to point out that the orthographic net was the proper net for constructing drawings of crystals in orthographic projection. He developed a very simple method for making such drawings (1917, fig. 4) and of constructing any given axial cross. This method is the basis of the construction given by Barker (1922, pp. 49–54) and Phillips (1946, pp. 214–18).

The three projection-nets—gnomonic, stereographic, and orthographic—are closely interrelated and can be derived one from another. The method of transposing a point on a stereographic net to its equivalent position on an orthographic net is described below.

3. USE OF ORTHOGRAPHIC NET IN CONSTRUCTING A SOLID ANGLE IN ORTHOGRAPHIC PROJECTION

Since all points on the fundamental sphere are at the same distance from the centre of the sphere, lines joining any points on the projection-net to the centre of the net are projections of lines of equal length. The three points *a*, *b* and *c* (Fig. 2) are thus the projections of three mutually inclined lines of equal length meeting at point O. The angles α, β, and γ between the lines can be read off along the arcs of the great circles[1] shown. The three lines thus enclose a solid angle, seen in orthographic projection, at a definite inclination to the plane of projection.

From Fig. 2 it will be seen that it is possible to construct a solid angle, consisting of any number of lines at any given inclinations to each other and to the plane of projection, so that unit length along each line is accurately known. As an example we shall consider the solid angle which will usually be required for a simple block diagram: viz. three mutually perpendicular axes at an angle to the plane of projection which depends on the chosen angle of sight. From such a solid angle it will be possible to construct a rectangular block in orthographic projection.

[1] On the orthographic net the great 'circles' are ellipses. Since, however, these are projections of great circles on the fundamental sphere, they will be referred to throughout this paper as great circles.

In order to see all three faces of the block, all the orthogonal axes forming its edges must be inclined to the plane of projection. Also, since it is common practice for one edge to be vertical and the top surface visible, the solid angle will be plotted in the lower hemisphere of the projection. The net is oriented with its polar diameter in the east–west position. The inclinations to the plane of projection of the three axes, *a*, *b* and *c*, is best described in terms of rotation about the east–west and north–south diameters of the projection-net (Fig. 3). The three axes are shown (Fig. 3 a) projected along a line parallel to *a* while *b* and *c* lie in the plane of projection. First the axes are rotated through an angle, *x*, around the north–south diameter of the net, so that *b* moves away from the primitive circle and *a* from the centre of the projection (Fig. 3 b). A second rotation (*y*) around the east–west diameter inclines the plane *ab* and displaces *c* from the

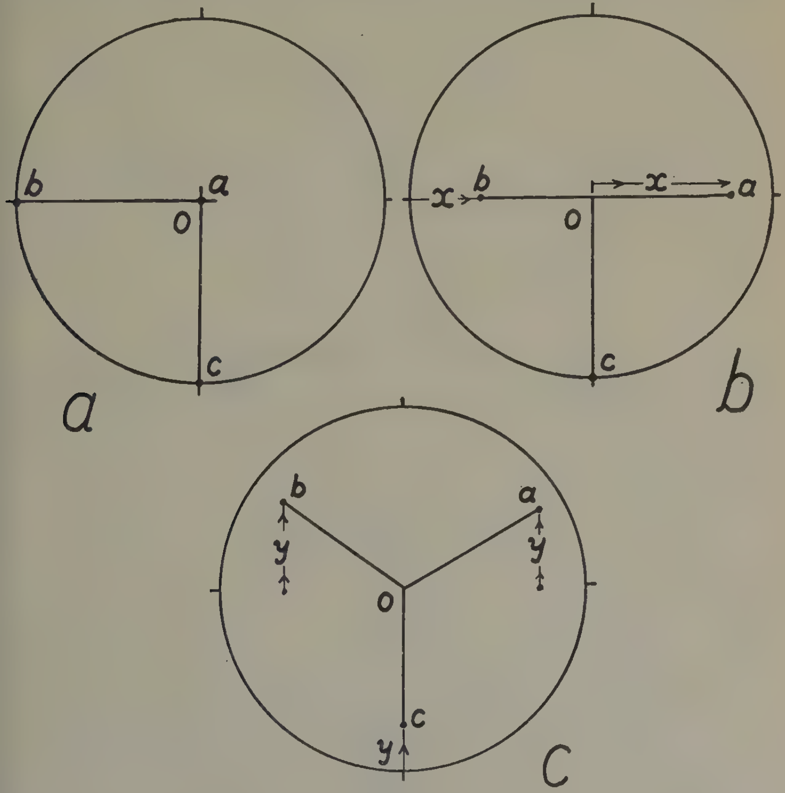

Fig. 3. Orthographic projection (lower hemisphere) of three orthogonal axes, *a*, *b*, and *c*, intersecting at *O*. (a) projection on *bc*-plane; (b) rotation of *x* around N–S. diameter; (c) further rotation of *y* around E–W. diameter

primitive circle (Fig. 3 c). All three axes are now inclined to the plane of projection according to the given angles x and y. The choice of x and y will depend primarily upon the relative importance of the data to be represented on each face.

To show how the construction can be made directly, without the intermediate steps given in Figs. 3 and 3 b, an example may be considered in which $x = 30°$ and $y = 40°$ (Fig. 4). Oc can be drawn along the north–south diameter of the net so that c is 40° from the primitive circle. The trace of plane ab is given by the great circle of which c is the pole. Now b and a lie on this great circle, b 30° from the primitive circle and a 90° from b, measured along this great circle. The positions of all three axes are now determined. Also, *since the lines on the net are projections of lines of equal length, we know the scale along each axis.*

For three axes mutually inclined at angles other than 90° the procedure is similar, although it is simpler to make the rotations through angles x and y as separate steps, in such cases. To achieve a required final inclination of the axes to the plane of projection, the values of x and y will depend upon the initial position from which these rotations are to be made. If the three axes are again labelled a, b and c, the initial position should be with c lying on the primitive circle at the equatorial diameter, and either the plane ac normal to the plane of projection, or the plane bc parallel to this plane.

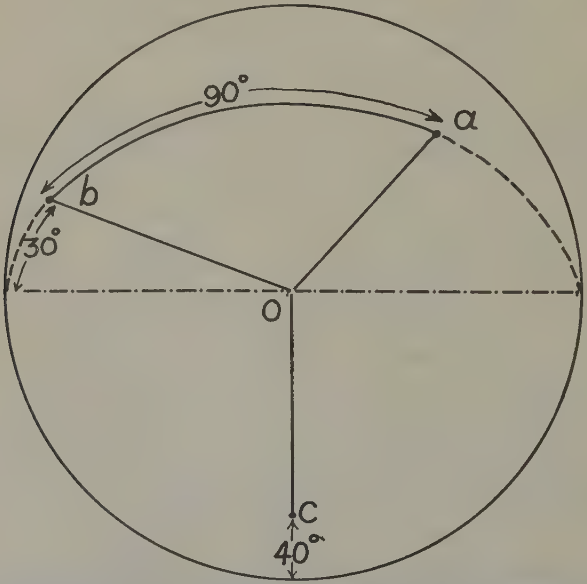

Fig. 4. Orthographic projection (lower hemisphere) of three orthogonal axes, *a*, *b*, and *c*, intersecting at O; $x=30°$, $y=40°$

4. CONSTRUCTION OF A BLOCK DIAGRAM, TO SCALE, FROM GIVEN DATA

To illustrate the method of constructing a block diagram from a projection of a solid angle, an actual example will be taken (Weiss, McIntyre & Kürsten, 1955). The following data are given:

A series of granulites and mica-schists above is separated from a body of quartzite below by a layer of mica which marks a slide. The granulite and mica-schist series is folded in small monoclinal folds which have the slide as a plane of *décollement*. The axial-surfaces[1] of these monoclines are parallel planes striking 72° and dipping 48°N. The axis of the folds (B_2) trends 257° and plunges 9°W. The quartzite below the slide is folded in superposed recumbent folds about an axis (B_I) trending 348° and plunging 6°N. A marked lineation, defined by the alignment and elongation of small grains, is parallel to this axis. The axial-surfaces of the folds are parallel planes striking 19° and dipping 12°WNW. In the micaceous layers a foliation is developed parallel to the axial-surface of the folds.

S_I foliation in quartzite folded about B_I.
S_2 foliation in micaceous layers in quartzite, parallel to the axial-surface of folds about B_I.
S_3 foliation in granulite–mica–schist series folded about B_2.
S_4 the slide, parallel to S_2 and containing B_I and B_2.

In the field, sketches were drawn, to scale, from faces of known orientation, to show in two dimensions the form and dimensions of the structures concerned.

A block diagram is to be constructed in the form of a square (tetragonal) prism, of length equal to twice the side of the square face, and oriented with the long edges north–south and the short edges vertical and horizontal respectively. The angles of rotation of the plane of projection from a vertical east–west plane (parallel to the square face of the block) are $x = 28°$, and $y = 18°$. A solid right angle is constructed as described above (Fig. 5 a), and the three lines OW′, ON′ and OV′ are oriented east–west, north–south and vertically respectively. These lines are traced on to another sheet and form one corner of the block in orthographic projection. Moreover, since these three lines are projections of lines of equal length, the scale along each is known, and the block can be constructed by means of a parallel rule. From the three initial lines, the actual lengths of which will depend upon the diameter of the orthographic net used, it is possible to construct the block to any actual size and with any required habit. The block diagram shown in Fig. 5 b has been constructed so that OW = 2.0W′, OV = 2.0V′ and ON= 4.0N′. The block has the required dimensional ratios, therefore.

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[1] For discussion of the terms *fold-axis*, *profile*, *hinge* and *axial-surface*, see Clark & McIntyre, 1951.

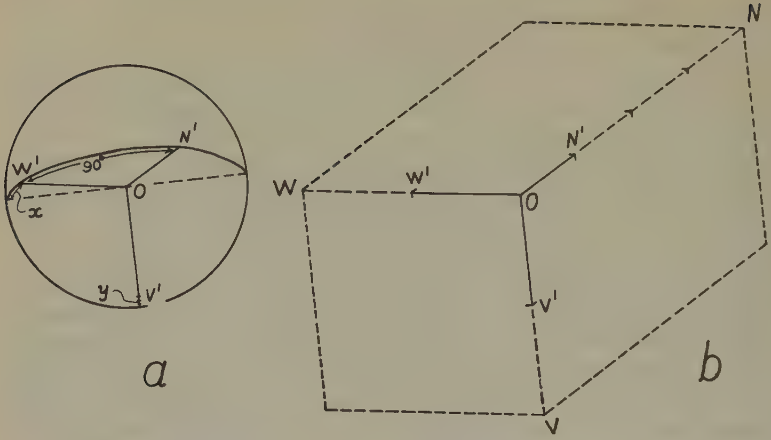

Fig. 5. Construction of a diagram of an orthogonal block, edges 1 x 1 x 2, seen in orthographic projection. Viewpoint given by *x* and *y*

On to this outline block diagram the form and relative dimensions of the structures to be represented must now be transferred from the field-sketches in correct orientation and perspective. The complex example here considered is unusual in that field-sketches made from two differently oriented faces must be employed. The reason for this is that two systems of folding about axes which are nearly mutually perpendicular are involved. Frequently a block diagram can be constructed from one field-sketch only. In order to make an accurate construction from two or more field-sketches, the latter should have a point in common. In the present example they have a plane in common (S_4). This plane has the same orientation in the adjacent localities from which the sketches were prepared, and in order to construct a block including both localities the portion above S_4 has been moved slightly southwards along S_4 with respect to the portion below S_4.

One of the field-sketches shows the form and relative dimensions of folds about B_I; the other of folds about B_2. Both sketches include S_4. The faces sketched are neither normal to the fold-axes nor parallel to any face of the block. However, since the trend and plunge of both fold-axes are known, it is possible to project the sketches on to planes parallel to any face of the block. Face WOV is nearly normal to B_I so the sketch showing folds about B_I will be projected on to this plane, as viewed normally. Similarly, face VON is almost normal to B_2, and the sketch showing the folds about this axis will be projected parallel to B_2 in the same manner. In the particular case described here, there are exposure-surfaces which are nearly parallel to faces of the block. Since only a small correction is required in the field-sketches to effect their projection on to these faces, we shall describe the procedure to be employed in an hypothetical general case.

Example illustrating the general case of axial-projection: i.e. projection from one plane to another not at right angles or parallel to the first, both planes being oblique to the fold-axis. In the stereographic projection (Fig. 6), the orientations of Planes 1 and 2, and of the fold-axis, are given. It is required to project, parallel to *B*, traces of form-surfaces[1] from Plane 1 on to Plane 2. Figs. 7 a, 7 b and 7 c represent Plane 1, Plane 2 and the Plane containing *B* and the normal to Plane 1 (i.e. P_1) respectively; in each case the planes are viewed normally and the necessary angular relations can be read from Fig. 6.

X–Y (i.e. I) is common to Planes 1 and 2;
L–M (i.e. I_1) is common to Planes 1 and B–P_1; and
L–N (i.e. I_2) is common to Planes 2 and B–P_1.

It follows that the point *p* on Plane 1 projects, parallel to *B*, to the position *q* on Plane 2. It is thus a simple matter to draw a grid on Plane 1 (the axes

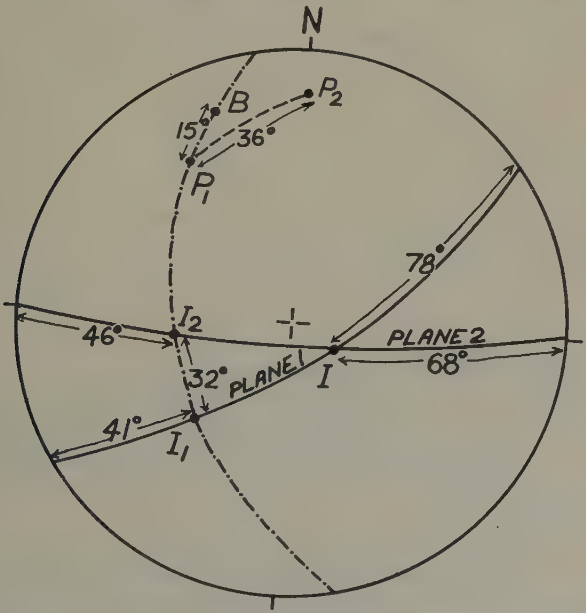

Fig. 6. Stereographic projection (lower hemisphere) of Plane 1 (Pole=P_1), Plane 2 (Pole=P_2), and fold-axis (*B*). Planes 1 and 2 intersect at *I*. The plane *B*–P_1 intersects Plane 1 at I_1 and Plane 2 at I_2

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[1] A *form-surface* is any surface selected to outline the form of a structure. It is analogous to a surveyor's *form-line*, i.e. a contour of unspecified altitude, usually drawn in by eye in the field.

of the grid being parallel to X–Y and L–M respectively) and to construct the equivalent grid on Plane 2 (the axes being parallel to X–Y and L–N respectively). Units on X–Y remain unchanged on the two planes. A distance s on L–M becomes t on L–N, where $t = s.\sin 75°/\sin 73°$. The necessary data consist of six angles which can all be read directly from a stereographic net by plotting three great circles.

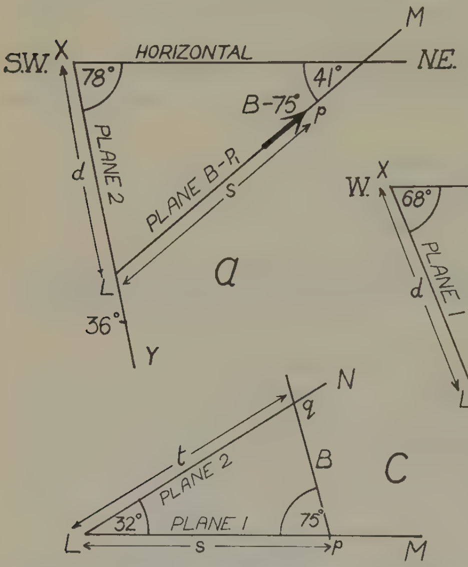

Fig. 7. (a), (b) and (c) represent Plane 1, Plane 2 and Plane B–P_1, respectively, viewed normally in each case. Point p on Plane 1 projects, parallel to B, to the position q on Plane 2

On the block diagram in orthographic projection, the faces are not viewed normally, but, since the scales have already been determined, it is easy to prepare the necessary grids to distort the sketches into orthographic projection so that they can be transferred to the appropriate faces of the block. Then it is possible to complete the block diagram by construction on the orthographic net.

The hinges of successive form-surfaces constituting one fold will intersect a given face along the trace of the axial-surface of the fold on that face. As an example of the construction, a fold about $B_{\rm I}$, seen on WOV and closing to the east about half-way down VO, will be considered. The closure of the form-surfaces on VON is required. Since $B_{\rm I}$ trends west of north, the closures appearing on VON will belong to form-surfaces with hinges passing to the east of edge VO; i.e. on the plane containing WOV these hinges (shown in broken lines in Fig. 8) will appear to the east of VO. The field-sketch must therefore include data from beyond the extent of the face WOV. The folds concerned are shown in orthographic projection in Fig. 8. The hinges of successive form-surfaces intersect the trace on VON of the axial-surface of the fold at points P_1, P_2, and so on. The trace of the axial-surface on VON can be determined on the orthographic net; the axial-surface and the face VON are plotted as great circles and the line joining their point of intersection to the centre of the net is the required trace (Fig. 9), which can be transferred directly to the block. The hinge of any form-surface is parallel to B_1; this can be plotted as a point on the net and joined to the centre to give a direction which may be transferred to any position in the block diagram as the orthographic projection of B_1 (Fig. 9). In this manner all the closures of S_1 falling on VON can be plotted accurately.

To find the traces of the folds about B_2 on faces other than VON the same procedure is followed, using the known orientation of the axial-surface of these folds and the known trend and plunge of B_2. The various traces required in the construction are again determined on the orthographic net (Fig. 9) and transferred directly to the block diagram with the aid of a parallel rule. When all the closures have been determined, the

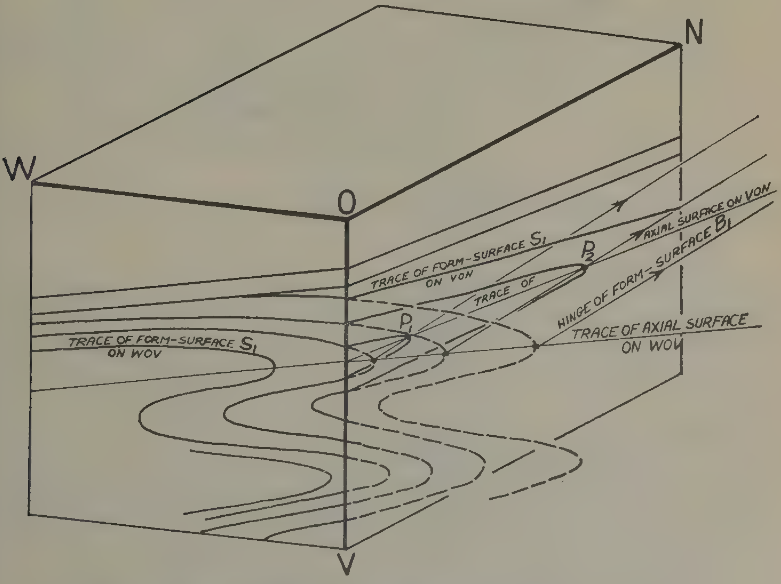

Fig. 8. Hinges observed on WOV, projected parallel to B_1 on to VON

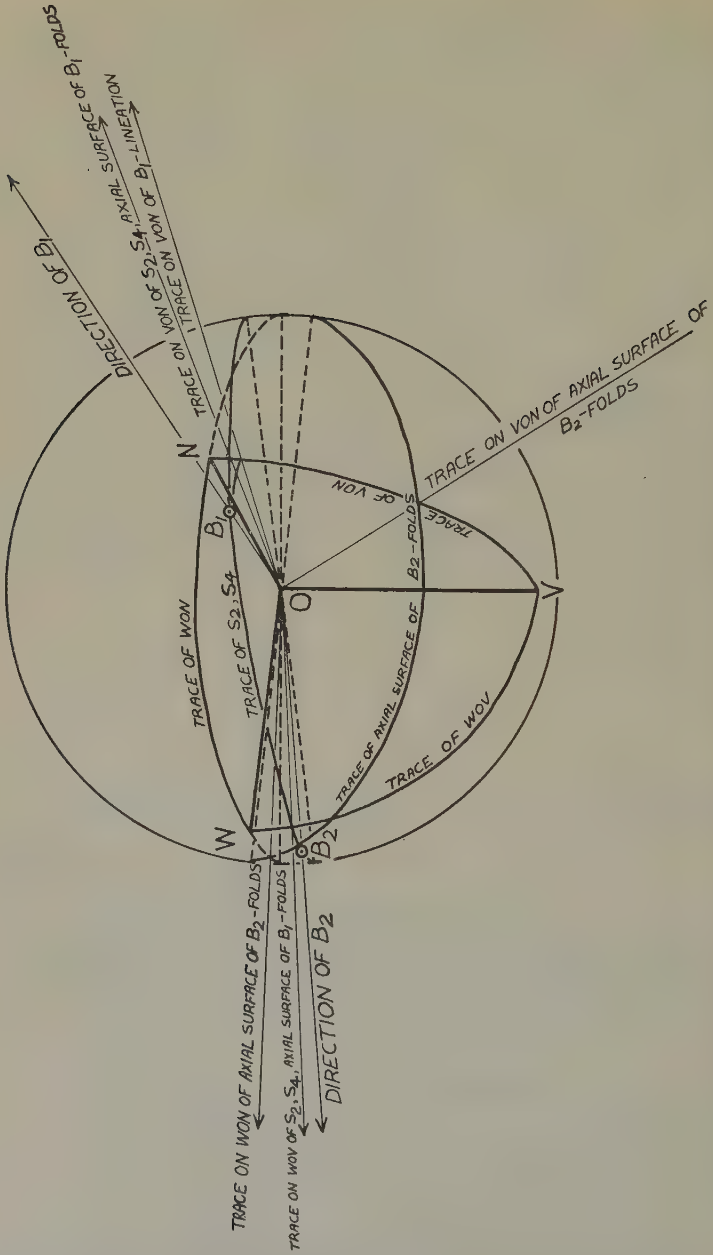
DIRECTION OF B1
TRACE ON VON OF S2, S4, AXIAL SURFACE OF B1-FOLDS
TRACE ON VON OF B1-LINEATION
TRACE ON VON OF AXIAL SURFACE OF B2-FOLDS
N
B1
TRACE OF VON
O
V
TRACE OF AXIAL SURFACE OF B2-FOLDS
TRACE OF WON
TRACE OF S2, S4
TRACE OF WOV
W
B2
TRACE ON WON OF AXIAL SURFACE OF B2-FOLDS
TRACE ON WOV OF S2, S4, AXIAL SURFACE OF B1-FOLDS
DIRECTION OF B2

Fig. 9. Orthographic projection (lower hemisphere) showing data necessary for construction of block diagram, Fig. 10

traces of the form-surfaces are drawn in on the three faces of the block in the diagram.

In order to complete the diagram all that remains to be inserted is the trace of S_2 on WOV and on VON (S_2 is parallel to S_4), and the trace of the lineation parallel to B_I on VON. The latter lies in the plane normal to VON containing B_I (Lowe, 1946; Clark & McIntyre, 1951a). The direction of the trace can be determined on the orthographic net (Fig. 9) and transferred to the block diagram directly. B_I is so nearly normal to WOV that the lineation parallel to B_I will leave no visible trace on it. There is no lineation parallel to B_2 to leave a trace on WOV or on WON. The completed diagram is shown in Fig. 10.

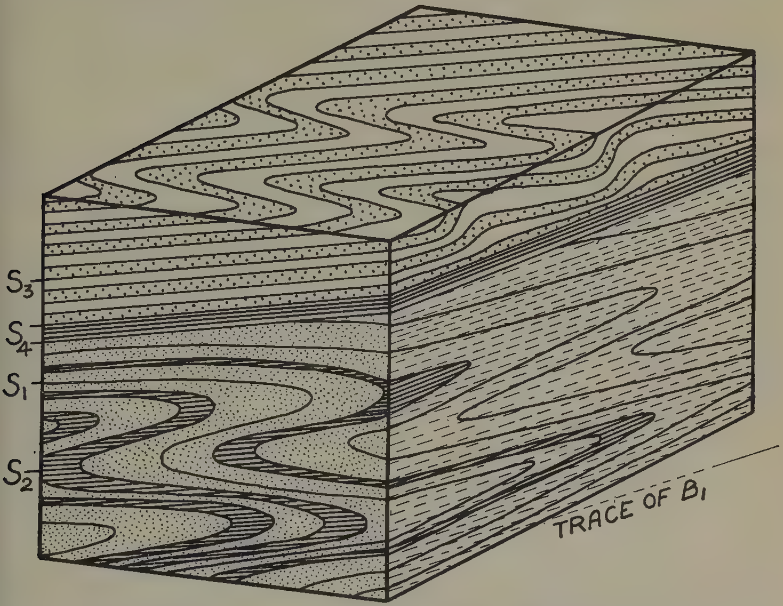

Fig. 10. Completed block diagram. Construction described in text.

Block diagrams of the kind described can be constructed in any shape or orientation. Also, the block may be parted along any given plane to facilitate a three-dimensional appreciation of the structures, and the angle of sight can be changed by simple rotation on the orthographic net. As a converse to the construction described, given a block diagram in orthographic projection, it is possible to read from the net the angle of sight and the scale along any direction in the diagram.

5. ALTERNATIVE CONSTRUCTION OF A BLOCK DIAGRAM, USING A STEREOGRAPHIC NET

If no orthographic net is available, all data can be plotted on a stereographic net and the relevant points transposed into the equivalent position on an orthographic net by a simple construction. The latter is shown in Fig. 11. Point S (Fig. 11 a) has been plotted on a piece of tracing paper lying over a stereographic net. To transpose it to the equivalent point in orthographic projection, the tracing paper is rotated until the point lies on the polar diameter of the stereographic net (PP′ in Fig. 11 b). From the intersection, S′, of the primitive circle with the small circle through S, a normal is drawn to the polar diameter. The point of intersection, O, is the required position of S in orthographic projection. This simple construction can readily be understood if Fig. 11 b is considered as a section of the fundamental sphere normal to the plane of projection (see Sommerfeldt, 1906).

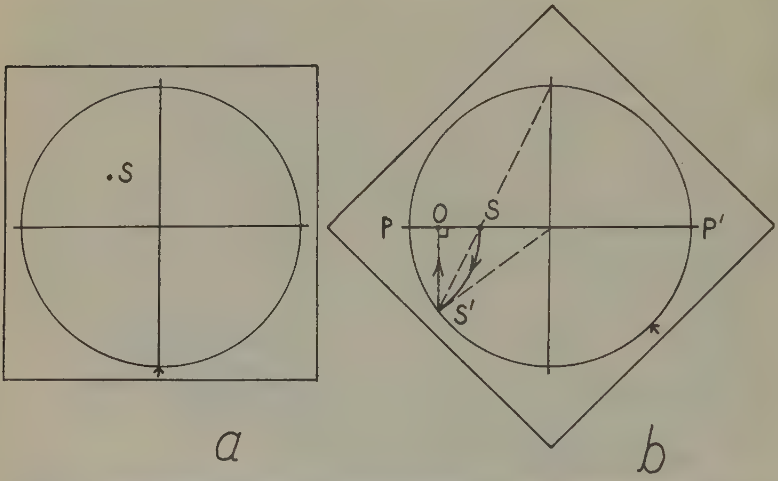

Fig. 11. Transposition of point S in stereographic projection to equivalent point, O, in orthographic projection

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Note on Shear Phenomena Associated with Flints in the Turonian near Royston, Hertfordshire

by J. T. O'B. PERRY

Received 3 December 1954

THE LOCALITY DESCRIBED is a fresh cutting in the upper part of the Middle Chalk, about three-quarters of a mile south of Royston, Hertfordshire, exposed during the recent widening of the Royston–Ware road (A10) (Geol. Surv. 1 in. Sheet, New Series, No. 204 Biggleswade).

According to the Geological Survey, the exposure lies immediately below the Chalk Rock horizon. This is borne out by the lithology, but the faunal evidence is inconclusive, and the Chalk Rock itself is not exposed. The cutting, which is on the east side of the road, extends for about a quarter of a mile, and has a maximum depth of approximately 25 ft., though the thickness of strata exposed is considerably greater than this on account of the southerly dip. It was cut during September and October 1954. Also the west side of the road is due to be widened shortly, which will possibly result in the exposure of the Chalk Rock and provide further opportunity for collecting fossils.

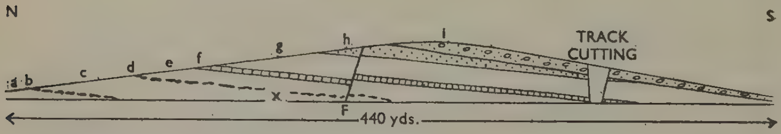

Fig. 1. Sketch section along the cutting (vertical scale approximately six times that of horizontal scale)

a. Soft white blocky chalk, with numerous flint nodules.
b. First band of tabular flint.
c. Soft white chalk, occasionally stained, and containing chalk nodules.
d. Second band of tabular flint.
e. Soft white chalk, similar to 'c'.
f. Band of chalk weathering white, and with thin marl seams in it.
g. Soft white chalk, with rusty-orange coloured staining along the joints.
h. Broken chalk with many large nodular flints.
i. Rubble and glacial drift, becoming earthy towards the top.

In the existing cutting quite soft, white chalk is exposed, with two main bands of tabular flint and scattered nodules of flint. The chalk is stained a rusty-orange colour in places, especially towards the middle and south end of the cutting, and there are one or two minor faults with downthrows of 9–18 in. to the north. The following fossils were obtained from the exposure:

Orbirhynchia sp.	immediately below first tabular band
Inoceramus fragments	
Terebella lewesiensis	
Bryozoa sp.	
Spondylus spinosus	from above marl band 'f' (Fig. 1)
Ostrea sp.	encrustation on *Spondylus*

Some of the elongated tabular flints from this locality are of interest (Figs. 2–4). Fig. 2 represents a flint from the point 'x' on the sketch section. It is 5 in. long, roughly elliptical in cross-section, with major and minor axes $1\frac{3}{8}$ in. and 1 in. in length respectively. These measurements include the compacted and sheared chalk which encases the flint itself (see Fig. 2a). The core of the flint is black, surrounded by a white cortex, somewhat less than $\frac{1}{10}$ in. in thickness, which grades into compacted chalk that forms a sheath round the flint $\frac{1}{12}$–$\frac{3}{8}$ in. in thickness. There is no patina. The chalk shows a certain degree of polishing and well-marked longitudinal striations which run the whole length of the flint, and follow

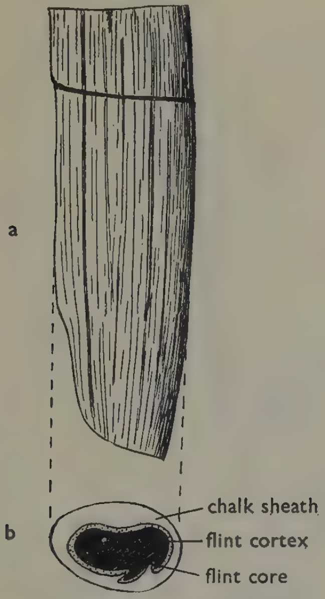

Fig. 2. Flint surrounded by a sheath of grooved and polished chalk (×0·47)

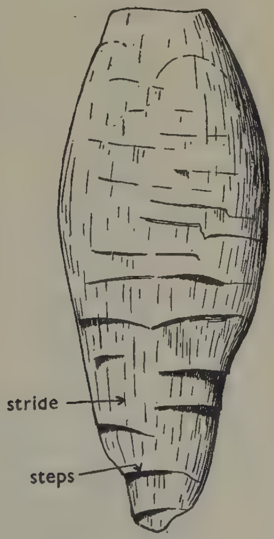

Fig. 3. Flint surrounded by concentric cylinders of striated chalk (×0·60)

the direction of tapering. These striations do not affect the flint itself, but occur in the chalk sheath, which, though harder than the main body of surrounding chalk, is unsilicified and has been compacted against the harder flint within it.

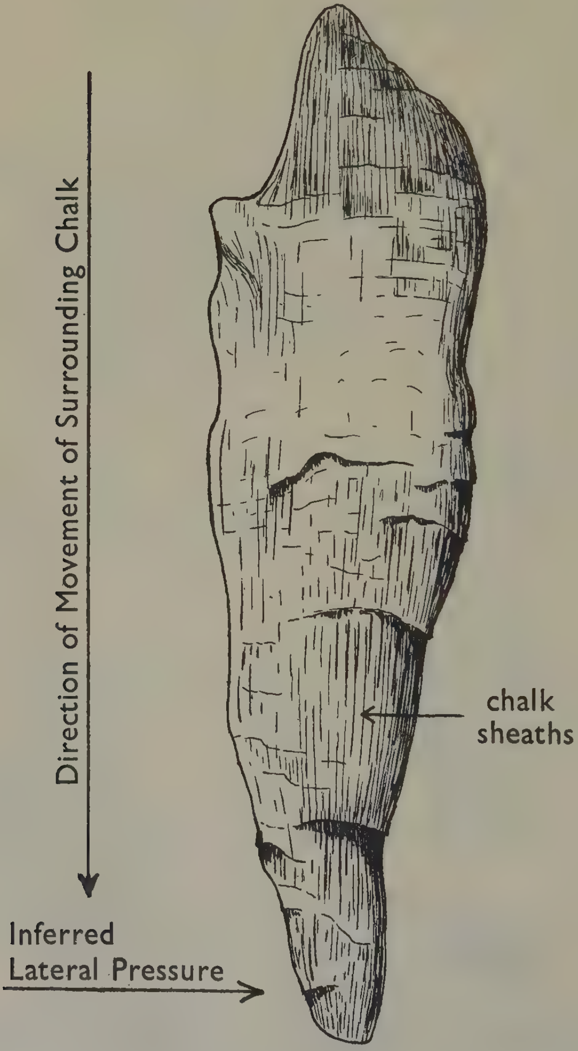
Direction of Movement of Surrounding Chalk
chalk sheaths
Inferred Lateral Pressure

Fig. 4. Long flint, showing concentric cylinders of striated chalk (×0·50)

Since the flint was found in a vertical position, the striations (which very closely resemble the slickensliding often associated with fault planes in the Chalk) are presumably due to relative vertical movement of the surrounding chalk. In other words, compression of the main body of the chalk at this point reduced its vertical thickness by at least 5 in. after the flint had been formed, since any one striation can be traced throughout the whole length of the flint. This movement does not appear to have any connection with the minor faulting seen in the cutting.

The structure is similar to, if not identical with, the roughly cylindrical shear marks often found in the Chalk—especially around nodules in the Chalk Rock (F. H. Edmunds, 1938, *Proc. Geol. Ass., Lond.*, **49**, 192). Previously these structures have been termed 'stylolites', but, in this case, it seems that the presence of flint in the centre of the striations precludes any possibility of their being due to a solution effect such as is normally believed to produce stylolites in limestones.

In Fig. 3 and Fig. 4 are shown a related structure from the same locality.

The specimen illustrated in Fig. 3 is a flint 4½ in. long, more nearly circular in cross-section than the one shown in Fig. 4, but tapering considerably, and having a maximum diameter of 1¾ in. When found, the narrower end was directed downwards. It shows the same striae and concentric sheaths of chalk as in Fig. 4, but both are far less polished than those shown in Fig. 2. The sheaths seem to 'step down' in the same direction as the flint is tapered.

On the other hand Fig. 4 shows a flint 10¾ in. long with a maximum width of 2½ in. The specimen, found in a vertical position, has longitudinal striae, similar to those on the flint in Fig. 2 though less well developed.

The sheath of surrounding chalk exhibits a number of irregular steps, giving the appearance of concentric cylinders of chalk which become progressively shorter towards the middle of the flint.

Probably the striae are produced by differential vertical movement of the surrounding chalk, as seen in Fig. 2. The concentric cylinders around each flint seem to be due to lateral pressure. Although the grooving and polishing on the specimen shown in Fig. 2 are definitely akin to those of slickenslides, the possibility should not be overlooked that the striae represented in Figs. 3 and 4 are due to partial recrystallisation of the chalk in a preferred orientation, as the result of pressure between the flint core and the compacted chalk envelope. It is difficult to confirm or disprove this hypothesis on account of the difficulty of obtaining a sufficiently thin section of the soft chalk to examine between crossed-nicols.

My thanks are due to Mr. M. J. O'Hara for permission to describe the flint shown in Fig. 4 and to Mr. D. J. Woodhams for his assistance and help in collecting specimens.

Whitsun Field Meeting at Shaftesbury

4–8 June 1954

Report by the Director: B. H. MOTTRAM

Leaders: B. H. Mottram, J. M. Hancock and M. R. House

Received 1 December 1955

THE PRESIDENT and nearly thirty members of the Association took part in the Whitsun Field Meeting held at Shaftesbury, Dorset. The purpose of the meeting was to visit localities in the Vale of Wardour and the Mere Fault country in south-west Wiltshire and north Dorset. Exposures were seen in nearly all formations from the Cornbrash to the Chalk. Although the fine weather of Friday evening became generally unsettled by Sunday morning, the programme was carried through as arranged.

Friday evening, 4 June

A coach, with the Director and a few members who had gathered at Shaftesbury already, met the London party at 7.15 p.m. outside Salisbury Station. All members were handed maps of the district and the party set off for an introductory drive through the Vale of Wardour to Shaftesbury.

The route taken was through Wilton to Barford St. Martin, where the Vale of Wardour geologically begins, and thence to Fovant along the Upper Greensand dip slope, with the beautiful bare Chalk escarpment to the south. At Fovant the coach turned north, to make the first traverse across the Vale of Wardour and up through the Chilmark Ravine, passing the famous quarries in the Portland Beds (now closed). The road just south of Chilmark was followed. This runs along the crest of the Upper Greensand strike-ridge as far as Ridge village, from where it leads southwards on to the Purbeck Beds forming Lady Down and thence down to Tisbury, built on Portland Beds. West of Tisbury the road to Newton was taken which traverses the dip slope of the Portland Beds and from which extensive views opened to the south across the Nadder Vale to the southern Chalk escarpments of White Sheet Hill and Win Green. Finally the last traverse to the south was made by descending the Portlandian escarpment, here over 650 ft. high near Pyt House, on to Kimeridge Clay near Semley village, and then up the escarpment of the Upper Greensand which forms Hart Hill to reach Shaftesbury at about 8.30 p.m.

Saturday, 5 June

The day was spent visiting localities within the Vale of Wardour. The first stop was in Wardour Park to see two small sections. The first, about 300 yds. north-west of Ark Farm, is the only known spot within the Vale where the basal Gault is seen to rest on the Lower Greensand (934.267). The following section was seen:

			ft.	in.
Gault	Blue clay with nodules	seen to	3	0
	Nodular ferruginous layer	1 ft. 3 in. to	1	9
	Blue clay with small quartz pebbles towards the base		1	2
Lower Greensand	White, well-bedded sands, with carbonaceous layers	seen to	3	0

The party then walked a short distance to the west where they spent some time collecting numerous lamellibranchs from some disused shallow pits in the Portland Beds.

The next stop was at the Chicksgrove Quarry, south of the Nadder (964.296). Here the upper part of the Portland Beds, and their junction with the Purbeck Beds, are exposed. A description of this section by Miss Benett was published by Sowerby in 1818—one of the earliest geological sections to be described in detail. Numerous lamellibranchs were collected, mainly from the Chalky Series immediately below the *Chlamys* Bed at the top of the Portland Beds.

The party then moved to Teffont Magna for lunch, passing the charming village of Teffont Evias, built of the local Purbeck stone. After lunch the party halted beside the main road, half a mile east of Chilmark Church, to see the successive northern dip slopes of the Chalk, Upper Greensand and Purbeck Beds and to examine a trackside-exposure of flinty Upper Chalk, probably in the *planus* zone. The smashed Chalk here dips 50° N., but 100 yds. farther up the track it flattens to 15° N. Then the party drove to a shallow disused quarry on Lady Down which exposes Middle Purbeck Beds (961.307). In the upper part of this section is the well-known *Archaeoniscus* Bed. Several specimens of this Isopod were found.[1] Also the Director showed some members the plentiful Lower Greensand debris littering the surrounding fields.

Next the party visited a quarry in the Tisbury Building Stones (Lower Portlandian) on the Newton Road (933.291) one mile west of Tisbury. This is the only quarry in the Building Stones still being worked. Traces of the Ragstones can be found above it. Then the members travelled to the large disused quarries on the east side of Fonthill Lake where thick courses of chert appear in the Building Stones.

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[1] The best locality for *Archaeoniscus* in the Vale of Wardour is the badly overgrown quarry by the railway line west of Dinton Station (004.308) described by Andrews & Jukes-Browne (*Quart. J. geol. Soc. Lond.*, 50, 1894, p. 56). M.R.H.

After tea at Hindon the coach conveyed the party to a point one and a third miles south of the village. From there members walked westward to Knoyle Corner, 1000 yds. south of Sheephouse Farm. On the way the Director explained the physiography and showed members the swallet south of Ruddlemoor Farm. At Knoyle Corner (897.307) the transition between the Upper Greensand and Chalk was seen. Several specimens of *Schloenbachia* spp. were found in the sandy base of the chalk. On walking along Knoyle Ridge attention was drawn to the curiously deep valley of Combe Bottom, on the north side of the ridge. This appears to be a strike vale, eroded along the outcrop of the Lower Chalk. At East Knoyle the party rejoined the coach and returned to Shaftesbury.

Sunday, 6 June

The day was spent visiting exposures in the northern limb of the Wardour fold and along the Mere Fault between West Knoyle and Bayford. The party started the day at East Knoyle where they had left off the previous evening. Messrs. Hancock and House awaited the party in the chalk pit beside the Hindon road (887.310) with a display of fossils from the *planus* zone. The pit shows about 20 ft. of the *lata* zone and about 40 ft. of the *planus* zone. The Chalk Rock, 3 ft. thick, with three distinct lines of green and rust-stained chalk pebbles, forms a marked lithological feature at the base of the *planus* zone. In this district it is no more fossiliferous than is the main mass of the *planus* zone.

The party travelled via Milton and ascended Windmill Hill where a brief halt was made for the Director to point out features in the extensive view to the south and west and to show the Mere Fault country to be visited later in the day. After following the road from the Green to Chapel Farm, Upton, the party walked along the steep northern limb of the Upton Pericline, passing on the way an old pit showing Upper Greensand dipping 45° N. (870.323). A halt was made at the highest point, half a mile east of West Knoyle, to see the land forms due to the emergence of the Mere Fault and to compare the supposed peneplained Chalk surface to the north-west with the unroofed nature of the Upton Pericline to the south-east. Beside the road, 300 yds. north-east of West Knoyle Church, is a shallow chalk pit (862.328). Despite intensive searching, members were unable to find any fossils other than fragments of *Inoceramus*. This exposure is probably in the *cor-anguinum* zone, yet only 150 yds. to the south the Director was able to show some of the party the last exposure of the Upper Greensand before reaching Mere, demonstrating that the Mere Fault commences here.

The party re-assembled 300 yds. west-south-west of the church to see evidence of Upper Chalk and Kimeridge Clay outcropping within 10 yds.

of each other. A small pit in the clay was opened up and augering left no doubt as to the absence of all the intervening formations.

Members rejoined the coach and travelled west to Charnage Quarry, which is much enlarged since the Association last visited it in 1937. The Chalk Rock was seen again, and in the recent northerly extension several specimens of *Micraster* were found, sufficient to indicate that the *cor-testudinarium* zone is now being worked. Several members commented on a number of flint courses traversing the bedding planes obliquely.

After lunch in Mere the party assembled in Dead Maid Quarry on the outskirts of the town (803.324). This quarry was already disused at the time of the Association's last visit but has not deteriorated seriously. An abundant Lower Cenomanian fauna with *Schloenbachia* spp., *Mantelliceras* spp., and less commonly *Hyphoplites* spp., coincides with the lithological break marked by the 'Popple Bed' and ranges up into the Glauconitic Marl above.

Then the first Corallian inlier was visited in Zeals Park and the party was shown the faulted contact between the *Trigonia clavellata* Beds of the Corallian and the top siltstones of the Upper Greensand at a point just north of the rough stone footbridge (800.317). One member found a *Decipia* sp. in the *Trigonia* Beds.

Next the coach took the party by way of the main road through Zeals and Bourton as far as the Somerset county boundary. Having turned up the side road towards Penselwood Hill the party alighted at the Penselwood turn to see a second exposure of the Mere Fault. Here, in the road bank, blue Kimeridge Clay could be seen to abut against olive-coloured glauconitic Greensand. The landslipped country to the west, with dragged-down Corallian oolites, was then seen. A quarry in Lower Cornbrash on Sunny Hill was visited, from which the macrurous crustacean *Eryma ventricosa* (von Meyer) was obtained. The party stopped for tea at Bayford where a widening of the road had exposed Upper Cornbrash in which the Director has found *Macrocephalites* (*Kamptocephalites*) sp.

The return to Shaftesbury was made by crossing the Stoke Trister Corallian tongue and up the main Corallian escarpment at Cucklington to see a quarry in the famous Cucklington Pisolite. Two examples of *Perisphinctes* (*Dichotomosphinctes*) sp. cf. *antecedens* Salfeld were found *in situ* just above the pisolite.[1] Abundant examples of *Nucleolites scutatus* Lamarck were found in the pisolite.

Monday, 7 June

The third day was spent visiting exposures in the Cenomanian basement beds and Corallian in north Dorset and some Mere Fault exposures omitted on the previous day. The first stop was made at a small disused quarry on the north side of Melbury Beacon, two miles south of Shaftesbury (875.201). This exposure is partly overgrown but the Director had cleared sufficient of the section to enable the complete passage between the Upper Greensand and the Chalk Marl to be seen. There is no lithological break between the two formations and Lower Cenomanian fossils appear in the Upper Greensand some 6 ft. below the Chalk Marl. Unfortunately the few fossils to be found below this horizon, such as *Discoidea subucula* Klein, are of insufficient stratigraphical value to give an exact dividing line between Albian and Cenomanian. In the passage beds below the Chalk Marl, fossils—particularly ammonites—are abundant. In addition to the usual Lower Cenomanian ammonite fauna of this area, which includes *Schloenbachia* spp., *Mantelliceras* spp., *Hyphoplites* spp., and *Mariella cenomanensis* (Schlüter), there occur both *Scaphites obliquus* J. Sowerby and *S. equalis* J. Sowerby. As the ammonites are not concentrated into a thin basement bed but are spaced out over six to eight feet, this exposure is a suitable locality for determining the ammonite succession for this part of the English Lower Cenomanian.

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[1] We are indebted to Dr. W. J. Arkell, F.R.S., for identifying all the Corallian ammonites mentioned in this report and to Mr. C. W. Wright for assistance in identifying many of the Cretaceous ammonites.

After members had collected enthusiastically from here the coach took the party to Gains Cross (842.100), one mile south-east of Shillingstone in the Stour Valley. Next the party walked to an awkward and concealed exposure, found accidently by the Director before the war, on the south-east bank of the Stour, about 600 yds. south of Hanford House (846.106). Amongst the trees and badger holes are several exposures of the Upper Greensand–Chalk Marl junction. Here there is no longer a continuous passage between the two formations but a return to the conditions seen at Dead Maid Quarry, Mere: basal Chalk Marl conglomerate with popples resting on a rust-stained erosion surface on the top of the Upper Greensand. Fossils are abundant in this basal bed but not particularly well preserved. It was pointed out that this is the last good exposure of the chalk basement bed before it becomes Middle Cenomanian in age, probably around Ansty, six and a half miles to the south-west. The ammonites from the chalk basement bed at Stour Bank include: *Idiohamites* sp., *Sciponoceras* cf. *baculoide* (Mantell), *Mariella* cf. *essensis* (Geinitz), *M.* cf. *lewesiensis* (Spath), *M.* cf. *cenomanensis* (Schlüter), *Hypoturrilites gravesianus* (D'Orbigny), *Ostlingoceras* cf. *puzosiforme* Spath, *Hyphoplites crassofalcatus* (Semenow), *H. curvatus* (Mantell), *H. pseudofalcatus* (Semenow), *Schloenbachia varians* (J. Sowerby), *S. varians* var. *tetrammata* (J. de C. Sowerby), *S. subtuberculata* (Sharpe), *S. subvarians* Spath, *S.* cf. *intermedia* (Mantell), *Mantelliceras* cf. *mantelli* (J. Sowerby) *M.*? cf. *cantianum* Spath, *M.* cf. *hyatti* Spath, *M.* cf. *tuberculatum* (Mantell) and gen. nov. allied to *Calycoceras*. The assemblage is comparable with that known from the Glauconitic Marl of the Isle of Wight.

On returning to the coach the party was met by the Rev. J. Fowler who led part of the 1939 Whitsun Field Meeting of the Association to Yeovil and the Sherborne area. He raised a question about the Stour gap. The general opinion, shared by the Director, was that the gap was not faulted, but further work could well be done here. In particular, the source and origin of the rounded chert gravels resting on the top of Shillingstone Hill over 600 ft. above the valley floor, and referred to by Osborne White in the *Shaftesbury Memoir*, need investigating.

The party now travelled north-west to Sturminster Newton, north along the Corallian cuesta to Marnhull and thence to Todber crossing the presumed old abandoned Stour Valley between the two villages. After lunch the party examined the two quarries exposing the false-bedded Todber Freestone just west of the school (797.198). In the south face of the southern quarry there is a small thickness of loose rubbly limestone above a massive *Pseudomelania* Bed. An ammonite, found loose by one member and apparently from this rubbly limestone, has been identified as *Perisphinctes* (*Arisphinctes*) aff. *osmingtonensis* Arkell, indicating the *Trigonia clavellata* Beds. The only other ammonite known from this quarry (also found loose), a *Perisphinctes* (*Dichotomosphinctes*) *antecedens* Salfeld, is probably from the Todber Freestone.

The party then drove to Whistley Farm near Silton, two miles north-west of Gillingham. About 300 yds. west of the Farm is a shallow disused quarry (782.285) in the *Trigonia clavellata* Beds. Lamellibranchs are abundant but there is no sign of *Mytilus varians* Roemer which forms a mussel bank at Manor Farm only 850 yds. to the north. The quarry exposing this bank was visited by the Association in 1937 but has now been filled in.

In addition to the many lamellibranchs, a few gastropods and an occasional echinoid, several ammonites have now been found at the Whistley Farm quarry. These include: *Decipia* aff. *lintonensis* Arkell, *D.* cf. *decipiens* (J. Sowerby), *Perisphinctes* (*Pseudarisphinctes*) cf. *shortlakensis* Arkell, *P.* sp. indet. cf. aff. *decurrens* Buckman, *Perisphinctes* sp. (cf. pl. VII, fig. 4, in Arkell, 1935–48, *Monograph of the Corallian Ammonites*).

The last stop before tea in Mere was for the purpose of seeing several exposures associated with the Mere Fault at Wolverton. After being shown the horizontal Upper Greensand on the downthrown side, the party made a short tour over the north-east corner of the Wolverton Corallian inlier during which the Director picked up a *Perisphinctes* cf. *antecedens* Salfeld from field rubble (787.311).

Tea was obtained at Mere and the President took the opportunity of thanking the Directors and wishing them luck in their future researches. Mr. S. W. Hester, who acted as Secretary for the meeting, was also warmly thanked. On the return to Shaftesbury a stop was made at the Gillingham

Brick Pit. Kimeridge Clay of the *baylei* and *cymodoce* zones are exposed. Despite steady rain, members found several fossils including one *Pictonia.*

Tuesday, 8 June

The last day of the Field Meeting was spent viewing the physiography of the downland country flanking the Chalke Valley and visiting exposures in the Gault at Fovant, the Upper Greensand at Dinton and Upper Chalk outside Salisbury. The first stop of the day was on the top of Rushmoor Down, south of Berwick St. John, where remnants of a possible peneplain can be seen. Visibility was good enough for the next Tertiary fold to the south to be picked out, marked by the distant Purbeck Hills and the western end of the Isle of Wight, between thirty and forty-five miles away. After rejoining the coach the party descended into the confines of the Chalke Valley at Berwick St. John and stopped to see a roadside exposure of Upper Greensand in the Alvediston inlier. At Ebbersbourne Wake the coach took the party on to the southern escarpment once more and good views were obtained of the periclinal vales of the Lower Chalk riding on the southern limb of the main Wardour fold. At Woodminton Down the route turned north again for a complete traverse across the Bower Chalk–Upper Greensand inlier, over the intervening syncline of Upper Chalk and across the succeeding long dip slope and down the main southern Wardour escarpment to Fovant.

The party walked to the north-west end of the village where there is a small pit on the north-east side of the Watercress Beds (002.290). This section shows some 12 ft. of the silty rock forming passage beds between the Gault and Upper Greensand. The Gault can be seen in the bed of the stream beside the pit.

This is the only good exposure of these passage beds in the Vale of Wardour. Mr. J. T. O'B. Perry of Salisbury, who discovered the pit, has collected a number of fossils from which the fauna is now known to include: *Epihoplites* cf. *gracilis* Spath ? transitional to *Callihoplites*, *Prohysteroceras* (*Goodhallites*) sp., *Hamites* (? *Stomohamites*) sp., *Pinna robinaldina* D'Orbigny, *Grammatodon carinatus* (J. Sowerby), *Neithea quinquecostata* (J. Sowerby), *Limatula* cf. *fittoni* (D'Orbigny), *Panopea mandibula* (J. Sowerby), ? *Lima* (*Plagiostoma*) sp., *Scalaria dupiniana* D'Orbigny. This assemblage indicates the *Pervinquieria inflata* Zone and the *varicosum* or *auritus* Sub-zone.

After lunch at Fovant the party drove to Dinton. In the south-east corner of the cross-roads, 400 yds. north of Dinton Station, trenches for new houses had exposed a mixture of Wealden and Lower Greensand rocks which members took the opportunity of examining as they are rarely visible in the district.

To the north-east of the village the party examined a disused sand quarry 300 yds. west-north-west of Manor Farm (018.319) showing the middle part of the Upper Greensand. Fossils are generally scarce but near the top of the section is a bed about a foot in thickness largely composed of *Ostrea vesiculosa* (J. Sowerby). Dr. Cox informs us that the shells are largely silicified.

The coach then took the party to the large chalk pit at West Harnham (128.288) near Salisbury. This shows the upper part of the *pilula* zone and the lower part of the *quadrata* zone (of Brydone's classification). Members spent most of the time collecting from the upper belt of abundant *Offaster pilula* in the lower part of the upper stage of the pit. Above the marl band at the top of this belt *O. pilula* is rare and the marl band is generally taken as the boundary between the two zones. Several members found the zonal fossil and Mr. Handford, the quarry owner, had assembled a small collection of the common fossils for members to take away.

The coach then took the party to Salisbury Station where some members caught convenient trains. Some, however, took the opportunity of visiting the Salisbury Museum. After seeing the geological collections, which include the valuable Blackmore collection of Upper Chalk fossils, members were shown over the archaeological and other sections of the museum by the curator, Mr. H. de S. Shortt.

Field Meeting in the Chilterns

17 June 1956

Report by the Directors: B. W. AVERY and A. J. THOMASSON

Received 16 July 1956

THE OBJECTIVES of this excursion were to study certain problems of the stratigraphy and geomorphology of the Chiltern area covered by Geological Survey, New Series, 1 in. Sheets 238 and 255.

The first stop was at Chesham Bois (Grid Ref. 973996), where an exposure of 5–6 ft. of Clay-with-flints, overlying Upper Chalk, was examined in a new road-cutting on the south side of the Chess Valley about 50 ft. below the general level of the adjoining plateau. The section showed the true Clay-with-flints, as described by Whitaker (1889)—a reddish unctuous clay containing black-coated unworn flints in immediate contact with the irregular and piped surface of the chalk. Above this was a heterogeneous clay containing shattered flints and flint pebbles and enclosing lenticles of stoneless fine sandy clay.

At this point Mr. Avery gave the party a brief review of the published work relating to the Chiltern superficial deposits, citing the contributions of Whitaker, Jukes-Browne (1906), Sherlock & Noble (1912), and Barrow (1919). The results of detailed soil surveys, accompanied by mechanical and mineralogical analyses of samples from selected soil profiles, suggested that both plateau and valley drifts were modified by the addition of loess-like silt (0.002–0.05 mm. diameter) and were themselves the product of two interacting processes, viz:

(i) Solution of chalk beneath a pervious cover of *remanié* Eocene, Pliocene or drift materials, and accumulation above the junction of infiltrated clay.

(ii) Solifluction and frost action.

Slow formation of basal Clay-with-flints by the first process was initiated in mid-Tertiary times and continued during the Pleistocene, under favourable conditions, but much of the earlier-formed Clay-with-flints was incorporated in the stony Head which covers most of the plateau, overriding the remains of Eocene and Pliocene sediments and extending down the gentler valley sides.

At Cowcroft (985018) a shallow sand-pit on the north side of the hill showed the following succession:

	ft.	
3. Pebble bed	1	? base of London Clay
2. Brown sandy clay	2	Reading Beds
1. Pale and brown sands with occasional thin, but continuous, grey clay bands and a few black-coated flint pebbles	6	Reading Beds

All the beds dipped towards the north-east. The attention of the party was called to the work of George Barrow, who described sections through the middle of the Cowcroft outlier, unfortunately now obscured, which showed considerable disturbances in both Chalk and Reading Beds. By contrast, the present section, although nearer to the surface, was comparatively undisturbed. Barrow attributed the deeper-lying disturbances to a large ice-sheet moving from the west during some period before the deposition of Chalky Boulder Clay. The absence of erratics on this part of the Chilterns makes this proposition difficult to sustain.

Members pointed out that the upper layers of the section, containing festoons of pebbles, had been affected by frost-heaving under periglacial conditions.

After lunch at the 'Blue Ball', Asheridge, the party examined a sand-pit near Dundridge Farm, St. Leonards (Grid Ref. 916061), sited on a narrow, flat-topped ridge bounded by dry valleys and exposing 30–35 ft. of whitish sand with grey clay bands beneath the superficial flinty clay Head. The Directors recalled that, originally, while the pit had been excavated to a depth of 50 ft. without reaching Chalk, exposures in the western dry valley revealed Chalk scarcely 20 ft. below the plateau surface. The beds examined in the pit resembled Reading Beds sands at Lane End, Buckinghamshire in structure, lithology and mineral assemblage, and were believed to be of similar age, the evident features of disturbance, including minor faults, folds and clay breccias, being attributed to slumping soon after deposition. A full account of this section will appear in a subsequent communication.

The party then drove by way of the Lee and Great Missenden to Prestwood brick-works (862014) where a fresh 30 ft. exposure of plateau deposits was examined. At this point a superficial Head of flinty clay averaging 5 ft. in thickness is channelled into weakly laminated 'brick-earth' containing occasional flint flakes, pebbles and large sarsens. The whole succession closely resembles that described by Sherlock & Noble (1912) at Walters Ash, three miles to the south-west. The possible correlation of the 'brick-earth' with similar laminated deposits at Gaddesden Row and Caddington, in which W. G. Smith found Acheulian implements (Oakley, 1947), was discussed. The Directors drew attention to Barrow's (1919) contention that apparently water-laid brick-earths of this type were associated with 'pre-glacial' sink-holes in the Chalk, and suggested that they could conceivably represent a local facies of Reading Beds. Neither of these views was generally accepted and it appeared from the ensuing discussion that the nature and origin of these deposits might provide a subject for further investigation.

Finally the party walked across the dry valley of Little Hampden (864037), taking the road towards Cobblers Hill from Hampden Bottom Farm, and thence through the woods on the east side of Little Hampden, turning due west across the fields to Manor Farm. The attention of the party was drawn to the distinct asymmetry of many of the dip-slope valleys, in which the steeper slope tends to face west or south-west. Little Hampden Valley is a particularly good example of this. Copies of generalised slope maps of the Chesham district on a scale of 1:25,000 (constructed by C. D. Ollier, now of the Uganda Soil Survey), which showed that the phenomenon is widely developed in this part of the Chilterns, were distributed to the party. The pattern of slope deposits and related soils is markedly different on the two sides of the valleys. These were studied in detail during 1955 and it is expected that the results of this work will be published elsewhere. Calcareous soils are associated with the steeper slopes, while naturally acid soils occur on north- and east-facing slopes. Silty material is an important constituent of the soils on the lower parts of the gentler slopes, and may be wind-deposited (Soil Survey Report No. 8, H.M.S.O., 1955). It is believed that this pattern of slopes and soils is a result of uniclinal shifting of a down-cutting stream, the gentler slope being virtually a slip-off slope. This shift is not structurally controlled, and as the Chalk surface under the deposits is also strongly asymmetrical, the processes involved in the shaping of such a valley are erosional rather than depositional. The steeper slope would seem to have undergone parallel retreat in the manner described by L. C. King (1951). The exact reason for the difference in weathering and erosion between the opposite sides of these valleys is not known. Insolation is probably important and may have affected the rate of weathering. Thus, under peri-glacial conditions, slopes facing south-west may have experienced more frequent changes of temperature than those facing north-east, resulting in corresponding freezing and thawing, while the north-east facing slope remained permanently frozen, or thawed out for only a short period during the summer. Solifluction activity would have been more rapid and turbulent on the slopes facing south-west. However, S. C. A. Holmes commented that he knew of essentially similar valleys in the North Downs, where the chalky head at the foot of the west-facing steeper slope contained fossil land-snails indicating a temperate climate not appreciably different from that of the present-day. Thus the asymmetry may be a result of inter-glacial rather than of glacial conditions. The presence of similar valleys in both arid and temperate regions of North America seems to indicate that differential weathering as a function of aspect can occur in a wide variety of climates.

The party had tea in Chesham after which the Acting President, Dr. G. W. Himus, thanked the Directors and Secretary.

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The Annual Report of the Council of the Geologists' Association for the Year 1955

THE NUMERICAL STRENGTH of the Association on 31 December 1955, was as follows:

Honorary Members	18
Ordinary Members:	
Life Members (compounded) ...	175
Annual Subscribers	1724
	1917

During the year 168 new members were elected, and the Association lost 134 members through death, resignations and removals under Rule XI for failure to pay subscriptions. Two members were reinstated.

Thus the membership has increased by thirty-six.

The list of deceased members is as follows: M. H. Ashworth, L. Merson Davies, C. H. Dinham, G. C. Dixon, G. W. Grabham, D. S. Haig, P. F. Hutchins, Miss M. S. Johnston, The Hon. Mr. Justice Kimball, G. M. Lees, E. C. Martin, F. C. Molesworth, E. A. Oliver, Stanley Smith and Prof. H. M. Turnbull (J. T. Hewitt, H. J. Osborne White and S. Priest, 1954).

Obituary Notices are published on pages 195–208.

FINANCE

There was some improvement in payment of subscriptions in 1955, but there were still fifteen per cent of Ordinary Members in arrears at the end of the year. In addition the estimated figure of £250, the value placed on the arrears at the end of 1954, fell short by over £70, and Sales of Publications were considerably down.

The estimated figure for the cost of the PROCEEDINGS includes an item of £1400 to cover the double part issued in December and the two parts for 1955 to be issued in 1956. A further transfer has been made to the Indexing Fund in order to meet the cost of the new list of members now being printed.

Expenses were up on last year and as the main expenditure is on printing and paper there is little hope of any improvement in 1956. If the fifteen per cent of the membership who are lagging with their subscriptions paid up, the Association might, with the help of the new members coming along, just pay its way in 1956. If this support be not forthcoming the extent of the Association's publications must suffer or the reserves, which are not inexhaustible, will again be drawn on. As members will note, there is a deficiency of £228 6*s*. 8*d*. for the year which has been met from reserve.

The Council of the Royal Society has again assisted the Association with a grant of £300 from the Parliamentary Grant in aid of Scientific Publications.

A legacy has been received under the will of the late Miss M. S. Johnston of £1000. On the Trustees' recommendation this has been invested in three and a half per cent War Loan.

BALANCE SHEET AT 31 DECEMBER 1955

Statement 1

1954 £		£ s. d.	£ s. d.	£ s. d.
	TRUST FUNDS AND FUNDS FOR SPECIAL PURPOSES:			
4511	Capital: (Invested)		5511 12 4	
	(Uninvested)		68 0 0	
—				5579 12 4
	Accumulated Income:			
306	Bequest Fund (Statement 3) ...		341 19 8	
41	Centenary Fund (Statement 4)		80 18 1	
72	Compounding Fund (Statement 5)		138 9 6	
23	Illustrations Fund (Statement 6)		– – –	
122	Indexing Fund (Statement 7) ...		221 13 10	
151	Watts Charnwood Forest Fund (Statement 8)		154 19 0	
27	Foulerton Award Fund (Statement 9)		27 5 5	
42	G. W. Young Geological Investigation Fund (Statement 10)...		62 10 9	
29	Henry Stopes Memorial Fund (Statement 11)		37 1 8	
–	Miss M. S. Johnston **Legacy** (Statement 12)		21 12 8	
				1086 10 7
813				6666 2 11
	GENERAL FUNDS:			
798	Income and Expenditure Account (Statement 2)			569 7 8
£6122				£7235 10 7

1954 £		£ s. d.	£ s. d.	£ s. d.
	TRUST FUNDS AND FUNDS FOR SPECIAL PURPOSES:			
4511	Investments (Statement 13) ...			5511 12 4
4	Income Tax Recoverable		13 5 3	
809	Cash at Bank and Post Office ...		1141 5 4	
813				1154 10 7
5324				6666 2 11
	GENERAL FUNDS:			
–	Debtor—Post Office Savings Bank Interest		9 4 0	
250	Subscriptions in Arrears		200 0 0	
2	Admission Fees in Arrears ...		20 0 0	
960	Cash at Bank, Post Office and in Hand		1971 16 10	
1212			2201 0 10	
9	*Less* Admission Fees in Advance	– – –		
107	*Less* Subscriptions in Advance ...	89 0 0		
298	*Less* Accrued Expenses	1542 13 2		
414			1631 13 2	
798				569 7 8
£6122				£7235 10 7

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31 DECEMBER 1955

Statement 2

EXPENDITURE

1954 £		£ s. d.	£ s. d.
1531	'PROCEEDINGS' OF THE ASSOCIATION (ESTIMATED)		1660 9 6
	GENERAL EXPENSES:		
42	Accountancy	36 15 0	
–	Field Meetings Expenses	13 16 4	
2	Insurance	2 16 11	
55	Meetings Expenses	62 4 6	
167	Postages	172 9 5	
90	Printing and Stationery...	146 11 4	
188	Printing Monthly Circulars	249 15 0	
9	Sundries	6 6 9	
–	Typing and Duplicating	30 19 6	
553			721 14 9
2084			2382 4 3
100	TRANSFER TO INDEXING FUND (Statement 7) ...		100 0 0
176	SURPLUS		– – –
£2360			£2482 4 3
	DEFICIT FOR YEAR BROUGHT DOWN		228 6 8
	BALANCE, per Balance Sheet (Statement 1) ...		569 7 8
			£797 14 4

INCOME

1954 £		£ s. d.	£ s. d.
	ANNUAL SUBSCRIPTIONS RECEIVABLE:		
1391	Received for 1955	1468 7 2	
194	Received for previous years	176 14 0	
250	*Add* Arrears at 31 December 1955 £518 8 0 estimated to realise	200 0 0	
1835		1845 1 2	
230	*Less* Arrears at 31 December 1954 £808 3 6 estimated to realise	250 0 0	
1605			1595 1 2
	ADMISSION FEES RECEIVABLE:		
43	Received for 1955	74 0 0	
4	Received for previous years	10 0	
2	*Add* Arrears at 31 December 1955 £29 0 0 estimated to realise	20 0 0	
49		94 10 0	
3	*Less* Arrears at 31 December 1954	2 10 0	
46			92 0 0
–	POST OFFICE INTEREST		9 4 0
350	ROYAL SOCIETY GRANT: 1955		300 0 0
259	PUBLICATIONS SALES		208 12 4
100	TRANSFER FROM ILLUSTRATIONS FUND (Statement 6)		49 0 1
–	DEFICIT FOR YEAR CARRIED DOWN		228 6 8
£2360			£2482 4 3
	BALANCE, 1 January 1955...		429 15 7
	TRANSFER FROM GENERAL RESERVE		367 18 9
			£797 14 4

FUNDS FOR SPECIAL PURPOSES

BEQUEST FUND

Statement 3

	£	s.	d.		£	s.	d.
Balance, 31 December 1955 (per Balance Sheet)	341	19	8	Balance, 1 January 1955	306	8	5
				Investment Income (Statement 13)	35	11	3
	£341	19	8		£341	19	8

CENTENARY FUND

Statement 4

	£	s.	d.		£	s.	d.
Balance, 31 December 1955 (per Balance Sheet)	80	18	1	Balance, 1 January 1955	40	13	1
				Donation	5	5	0
				Investment Income (Statement 13)	35	0	0
	£80	18	1		£80	18	1

COMPOUNDING FUND

Statement 5

	£	s.	d.		£	s.	d.
Balance, 31 December 1955 (per Balance Sheet)	138	9	6	Balance, 1 January 1955	71	15	10
				Investment Income (Statement 13)	66	13	8
	£138	9	6		£138	9	6

FUNDS FOR SPECIAL PURPOSES (*Continued*)

ILLUSTRATIONS FUND

Statement 6

	£	s.	d.		£	s.	d.
Balance, 31 December 1955 (per Balance Sheet)	–	–	–	Balance, 1 January 1955	22	18	7
Transfer to Income and Expenditure Account	49	0	1	Investment Income (Statement 13)		12	6
				Donation and Subscriptions	25	9	0
	£49	0	1		£49	0	1

INDEXING FUND

Statement 7

	£	s.	d.		£	s.	d.
Balance, 31 December 1955 (per Balance Sheet)	221	13	10	Balance, 1 January 1955	121	13	10
				Transfer from Income and Expenditure Account	100	0	0
	£221	13	10		£221	13	10

WATTS CHARNWOOD FOREST FUND

Statement 8

	£	s.	d.		£	s.	d.
Balance, 31 December 1955 (per Balance Sheet)	154	19	0	Balance, 1 January 1955	150	11	0
				Sales of Books	4	8	0
	£154	19	0		£154	19	0

Trust Funds

FOULERTON AWARD FUND

Statement 9

	£ s. d.		£ s. d.
Award to Mr. C. W. Wright	10 0 0	Balance, 1 January 1955	26 15 9
Balance, 31 December 1955 (per Balance Sheet)	27 5 5	Investment Income (Statement 13)	10 9 8
	£37 5 5		£37 5 5

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND

Statement 10

	£ s. d.			£ s. d.
Income Tax Repaid to Public Trustee—1954	3 15 10	Balance, 1 January 1955		42 10 9
1955 (Estimated)	3 15 10	Interest Received from Public Trustee (Gross):		
Balance, 31 December 1955 (per Balance Sheet)	62 10 9	Year 1954...	13 15 10	
		Year 1955...	13 15 10	
				27 11 8
	£70 2 5			£70 2 5

HENRY STOPES MEMORIAL FUND

Statement 11

	£ s. d.		£ s. d.
Balance, 31 December 1955 (per Balance Sheet)	37 1 8	Balance, 1 January 1955	29 10 9
Engraving Medal	8 6	Investment Income (Statement 13)	7 19 5
	£37 10 2		£37 10 2

MISS M. S. JOHNSTON LEGACY

Statement 12

	£ s. d.		£ s. d.
Balance, 31 December 1955 (per Balance Sheet)	21 12 8	Investment Income (Statement 13)	21 12 8

SCHEDULE OF INVESTMENTS—31 DECEMBER 1955

	AT COST OR VALUE WHEN ACQUIRED		INVESTMENT INCOME (GROSS)	
	£ s. d.	£ s. d.	£ s. d.	£ s. d.
FUNDS FOR SPECIAL PURPOSES:				
Bequest Fund:				
£143 8 9 3½% War Stock	141 14 0		5 0 6	
£150 0 0 New Zealand 3½% Stock 1960/64	122 5 0		5 5 0	
£85 0 0 3% Defence Bonds	85 0 0		2 11 0	
£200 0 0 3½% Defence Bonds (converted from 3% in January 1955)... ...	200 0 0		6 10 0	
£100 0 0 3% Savings Bonds 1960/70 ...	100 0 0		3 0 0	
£441 5 4 3% British Transport Stock 1978/88	400 0 0		13 4 9	
		1048 19 0		35 11 3
Centenary Fund:				
£1000 0 0 3½% Defence Bonds		1000 0 0		35 0 0
Compounding Fund:				
£1217 2 6 Nottingham Corporation 3% Irredeemable Stock	1152 13 2		36 10 2	
£200 0 0 3% Savings Bonds 1955/65 ...	200 0 0		6 0 0	
£170 0 0 3½% War Stock	152 14 5		5 19 0	
£100 0 0 3% Savings Bonds 1965/75 ...	100 0 0		3 0 0	
£300 0 0 3½% Treasury Stock 1977/80...	282 2 0		15 4 6	
		1887 9 7		66 13 8
Illustrations Fund:				
£21 0 10 Metropolitan Water Board 3% 'B' Stock		20 0 0		12 6
TRUST FUNDS:				
Foulerton Award Fund:				
£349 7 0 3% British Transport Guaranteed Stock 1978/88		294 11 0		10 9 8
Henry Stopes Memorial Fund:				
£265 19 2 Government of Newfoundland 3% Stock 1943/63		260 12 9		7 19 5
LEGACY:				
Miss M. S. Johnston:				
£1236 4 6 3½% War Stock		1000 0 0		21 12 8
TOTAL INVESTMENTS, per Balance Sheet		£5511 12 4		

MARTIN, FARLOW & CO., *Incorporated Accountants.*

We have compared these Statements with the books and records presented to us and find them to agree.

We have also verified the Investments and Cash Balances held by the Association at 31 December 1955.

L. J. PITT, *Treasurer.*
December 1955.

W. S. PITCHER } *Auditors*
I. T. PRITCHARD }

PUBLICATIONS

Publications Committee. The Committee consisted of the seven Officers, Mrs. J. M. Eyles and Messrs. S. E. Hollingworth, Gilbert Wilson, E. E. S. Brown, H. Dighton Thomas and A. F. Hallimond.

The Committee met on five occasions and considered twenty-six papers on which reports were made to Council.

Proceedings. Part 4 of Volume 65 (for 1954) was published, bringing the total number of pages for this Volume up to 432 (compared with 316 for Volume 64).

Parts I and II of Volume 66 were published in a single binding in December.

MEETINGS

Nine Ordinary Meetings were held at which nine papers were read.

The thanks of the Association are due to the authors of papers and to the Geological Society for the use of its apartments throughout the year.

REUNION

The Annual Reunion was held at the Chelsea Polytechnic on Saturday, 5 November. A wide range of exhibits was shown and it was attended by over 300 members and their friends.

Thanks are due to the Principal and staff of the Polytechnic and the members concerned.

FIELD MEETINGS

The Committee consisted of the Officers with Mrs. Evans and Messrs. Vernon Wilson, W. Pitcher, A. G. Davis, D. V. Ager, W. E. Smith, D. Curry, G. W. Himus and J. F. Kirkaldy.

During the year there were four Demonstrations, two week-end, seven whole day and four half-day Field Meetings.

Easter and Whitsun Field Meetings were held at Settle and North Devon respectively.

Anglesey and the South Devon and Dorset coasts were visited for the Summer Long Field Meetings.

The thanks of the Association are due to the Directors and all others who organised and assisted at these meetings.

THE LIBRARY

The Library Committee consisted of the President, the Librarian, Mrs. Eyles, Mrs. Evans, Messrs. R. Reeley, M. K. Wells and J. W. Scott, Librarian of University College, London.

Gifts of books and pamphlets listed in the Sessions Report are gratefully acknowledged by the Association.

An exchange of publications was instituted with the Department of Geology and Mineralogy, University of Tokyo, and with the Geological Survey of P. R. Slovenia. The exchange with the Institut de Geologie de l'Université, Istanbul, was renewed after a lapse of two years.

NORTH-EAST LANCASHIRE GROUP

Chairman: J. Ranson, A.M.I.Min.E., F.G.S.

Secretary: Mrs. J. F. Ranson, B.A.

Committee: D. H. Learoyd, I. A. Williamson, N. Thompson, G. F. Urry.

During the year six meetings were held and there were five Field Meetings. Particulars are published in the Report of the Session.

Thanks are due to the Authorities of the Blackburn Technical College for the use of rooms.

MIDLAND GROUP

Chairman: A. Ludford, M.SC., F.G.S.

Secretary: Miss Grace M. Bauer, F.G.S.

Committee: A. F. Archer, D. R. Hughes, P. A. Garratt, C. S. Tighe.

During the year five meetings were held in the Geology Department, The University, Birmingham, and there were four Field Meetings. Particulars are published in the Report of the Session. Thanks are due to Professor Shotton for the use of the Geology Department at the University for these meetings.

NORTH STAFFORDSHIRE GROUP

Professor F. Wolverson Cope, D.SC., M.I.Min.E.

Chairman: J. T. Wattison, F.G.S.

Vice-Chairman: J. C. Parrack, B.SC., F.R.G.S.

Secretary: T. S. Purcell, B.SC.

Treasurer: J. T. Gleaves, B.A.

Field Secretary: J. Myers, B.SC., F.G.S., F.R.G.S.

Research Secretary: D. O. Thomas, F.G.S.

Committee: W. J. Adams, F.G.S., Dr. E. Berrer, Miss I. Cottier, T. S. Jones, F.G.S., P. S. Keeling, B.SC., F.R.I.C., A.R.S.M. (Press Secretary), E. A. Watkin.

During the year seven meetings were held, including the Annual Conversazione, and there were two Field Meetings. Details are published in the Report of the Session. Thanks are due to the Authorities of the Arts Centre, Newcastle-under-Lyme, for the use of rooms.

JAMAICA GROUP

Chairman: L. J. Chubb, PH.D., M.SC., F.G.S.

Vice-Chairman: S. A. G. Taylor.

Secretary: J. B. Williams, B.SC., F.G.S.

Treasurer: M. B. C. Scott.

Committee: Miss K. O. Cusack, E. L. Frater, G. V. Helwig, H. E. Vendryes.

The Inaugural Meeting, followed by a Dinner, was held in October, and a Field Meeting in November. Particulars are published in the Report of the Session. Thanks are due to the Institute of Jamaica for the use of rooms.

TRUSTEES

The Trustees of the Association were:

Managing: Mr. S. Hazzledine Warren, F.G.S., Dr. W. F. Fleet, M.SC., A.R.I.C., A.C.P., F.G.S., and Mr. Percy Evans, M.A., F.G.S. (appointed in place of Mr. E. C. Martin, deceased).

Custodian: The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD

The Foulerton Award for the year was given to Mr. C. W. Wright, M.A., F.G.S., in recognition of his services to Geology and the Association.

HOUSE LIST

Mr. A. J. Butler retires as Senior Vice-President and Dr. Hallimond and Mrs. Eyles as ordinary members of the Council.

Mr. R. Reeley resigns as Vice-President at his own request.

Thanks are due to these members for services rendered to the Association.

REPORT OF THE SESSION 1955

Ordinary Meeting, 7 *January* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

George Edward Allen, Mrs. Georgina Myrtle Baguley, Jerome Wylde Carter, Lester L. Fernandes, Miss Gillian Ailsa Finch, Harry James Fisher, Cedric C. Hanson, Isaac Allan Jenkins, Milton A. Lee, Miss Marie Howlett Lucas, Miss Mary Elizabeth Ridges, William Andrew Stinton and Mary Angela Theresa Williams were elected members of the Association.

Messrs. D. V. Ager and A. G. Davis were elected Auditors of the accounts for 1954.

The following lecture was given: 'Recent work on Pleistocene problems in North-West America', by G. A. Kellaway, B.SC., F.G.S.

Ordinary Meeting, 4 *February* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

Barry Stanton Dare, Barry Hughes, S. Mozaffer Husain, Arthur Jackson

Thomasson, Stanley Leonard Toyn, Rodney David Walshaw and Dudley Rowland Winslet were elected members of the Association.

The following paper was read: 'The geology of south-west Jersey', by F. A. Henson, B.SC., Ph.D., F.G.S.

The following papers were read in title: (a) 'Fish Otoliths from the London Clay of Bognor Regis', by F. C. Stinton, and (b) 'The use of sugar solution in the differentiation of the internal structures of upper chalk brachiopods', by E. F. Owen.

Annual General Meeting, 4 *March* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

The Annual Report of the Council (already circulated) was taken as read. It was moved by Mr. E. R. Martin, seconded by Mrs. B. Ainsley, 'That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1954'. The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of the Council in accordance with Rule XIII: *President*, L. R. Cox, M.A., SC.D., F.R.S., F.G.S.; *Vice-Presidents*, A. J. Butler, O.B.E., M.SC., F.G.S., T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., H. Dighton Thomas, M.A., Ph.D., F.G.S., G. W. Himus, Ph.D., F.G.S., R. Reeley, F.G.S.; *Treasurer*, L. J. Pitt, F.G.S.; *Secretaries*, General—F. H. Moore, B.SC., Ph.D., F.G.S.; Field Meetings: S. W. Hester, F.G.S.; Publications Committee: M. K. Wells, M.SC., Ph.D., F.G.S.; *Editor*, A. J. Dollar, B.SC., Ph.D., A.K.C., F.R.S.E., F.G.S.; *Librarian*, R. Bradshaw, M.SC., F.G.S.; *Eleven other Members of Council*, A. F. Hallimond, M.A., SC.D., F.G.S., Mrs. V. A. Eyles, B.SC., F.G.S., W. E. Smith, M.SC., F.G.S., D. Curry, M.A., F.G.S., S. Bracewell, B.SC., D.I.C., A.R.C.S., F.G.S., Gilbert Wilson, Ph.D., M.SC., D.I.C., F.G.S., Mrs. E. M. Evans, M.SC., F.G.S., Mrs. J. V. Harrison, M.A., B.SC., D. V. Ager, B.SC., Ph.D., F.G.S., S. E. Hollingworth, M.A., D.SC., F.G.S., J. F. Hayward, M.SC., Ph.D., F.G.S.

It was moved by Mr. D. J. Shearman, seconded by Dr. J. F. Hayward, and duly carried, 'That the best thanks of the Association be given to the Officers, the retiring members of Council, and the Auditors'.

The Henry Stopes Memorial Medal was handed to Mr. Colin Leakey for transmission to his father, L. S. B. Leakey, M.A., Ph.D., in Kenya, in recognition of Dr. Leakey's work on the prehistory of Man. The President said:

> Mr. Leakey: The Henry Stopes Memorial Fund was instituted in 1946 for the triennial award of a medal for work on the prehistory of Man and his geological environment, and on this occasion, the first on which the award has been made for work accomplished outside the British Isles, there could be no more fitting recipient than your father, Dr. L. S. B. Leakey, Curator of the Coryndon Memorial Museum, Nairobi.

As told in his own book, *White African* (1937), your father, son of a missionary, the Reverend Harry Leakey, was one of the first white children to be born in the highlands of Kenya, and his interest in the relics of the Stone Age found in East Africa dates from early boyhood. After reading anthropology at Cambridge, his first thought was to return to the study of the Pleistocene deposits of East Africa, and to this end he organised and led (from 1926 to 1935) four British expeditions, to Nakuru and Makalia, to Gamble's Cave, to Oldoway, and to Konam, Kangera and Rusinga. As a result, the sequence of Pleistocene faunas and industries of East Africa, our knowledge of which was previously almost lacking, was established and correlated with earth movements and climatic changes. I may mention that Kenya, Tanganyika and Uganda now form the type-area for the African sequence of pluvial and interpluvial periods, and that three out of the five pluvial phases now widely recognised in the continent (the Gamblian, Makalian and Nakurian) have been named after sites first investigated by your father.

In 1942 he discovered exposures of lake-side camping sites of Acheulian Man at Olorgesailie—one of the most spectacular archaeological discoveries of the century. In 1947 he organised the first Pan-African Congress on Prehistory. In recent years he has concentrated much of his phenomenal energy on the exploration of the fossiliferous Tertiary lake-beds in the Kavirondo region. From 1947 onwards he has acted as field director of the British–Kenya Miocene Expedition to the Kavirondo Gulf of Lake Victoria, and obtained large collections of fossil mammals. On Rusinga Island alone he collected in 1947 more than 100 specimens of Miocene apes—several times as many as are known from the rest of the world. The results of their detailed study, in which he collaborated with Sir Wilfred Le Gros Clarke, have been published by the British Museum (Natural History). Also he has studied, and published a report on, the Pleistocene Prehistory of Angola. More recently he has completed a monograph on the Pleistocene pigs of East Africa, now awaiting publication. Among his other works are his magnificent monographs on *The Stone Age Cultures of Kenya Colony* (1931), *The Stone Age Races of Kenya* (1935), *Stone Age Africa* (1936) and *Olduvai Gorge* (1951), and his well-known book *Adam's Ancestors* (2nd edition, 1953).

I ask you, therefore, to transmit this medal to your father as a testimony to his outstanding work, carried out, especially latterly, in exceptionally difficult circumstances. We look forward to the Stopes Memorial Lecture which he has promised to give on his next visit to this country.

The Foulerton Award was presented to Mr. C. W. Wright, M.A., F.G.S., in recognition of his work for geology and the Association. The President said:

Mr. Wright: It is now more than twenty-three years since the staff of the British Museum (Natural History) became aware of certain prognostications of the rise of a new star in the geological constellation. The prognostications were not themselves of an astronomical nature, but in the tangible form of frequent letters from a certain schoolboy, sent alternately from his Yorkshire home and his Surrey school, asking if he might send fossils for identification. Astronomical, however, was the number of fossils which duly arrived, and with which the Museum staff coped only by a superhuman effort. It was obvious that here was one whose enthusiasm was unbounded and whose collecting powers were altogether phenomenal.

> It will have been guessed of whom I have been speaking. Installed not (as might have been) in a Chair of Geology, but in the peaceful atmosphere of the War Office, you have already established an international reputation as an authority on Cretaceous palaeontology, and in particular on the ammonites and echinoderms of the System. You have made notable contributions to the stratigraphy of our Cretaceous rocks, many published in our PROCEEDINGS, and they show a breadth of knowledge and outlook derived, no doubt, from your connections both with Yorkshire and with southern England. Your papers (some written in collaboration with your brother, E. V. Wright) are already nearly fifty in number, and have flowed, not only from the presses of this country, but also from those of Menasha, Wisconsin, and Kinshin, Japan. The Association is particularly indebted to you for directing many Field Meetings and for your exhibits at our annual Reunion, which have shown other members that they need not despair of collecting good specimens even at the present day.
>
> The regulations governing the Foulerton Award state that, as far as possible, it should be made to encourage future work as well as to recognise past work. That you will accomplish much future work we can all be certain, and with such an enthusiast as yourself perhaps the comment could be made that encouragement is scarcely necessary. As one who has known you since the early days of which I have spoken, it is with the greatest pleasure and best wishes that I hand to you this year's Foulerton Award.

The President then delivered his address entitled 'British Palaeontology: a retrospect and survey'.

It was moved by Mr. Percy Evans, seconded by Mr. N. B. Peake, and duly carried, 'That the best thanks of the Association be accorded the President for his address'.

Ordinary Meeting, 4 *March* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

Miss J. K. a'Brook, Hugh Alexander Powle Fowler, B.A., Desmond James Gispert, John Roland Haynes, Ph.D., B.SC., Henry Miller, B.SC., Brian Seeley Norford and John David Solomon, M.A., Ph.D., F.G.S. were elected members of the Association.

Ordinary Meeting, 1 *April* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

George Rodney Collomb, B.A., Colin Lachlan Forbes, M.A., Ph.D., Richard Hugh Johnson, B.A., Walter Oldershaw, Derek Price, Charles Peter Randall, F.R.G.S., and Martin Theodore Te Punga, M.SC., Ph.D., F.G.S. were elected members of the Association.

The following papers were read by E. W. H. Culling: (a) 'The Longitudinal profiles of the Chiltern streams'; (b) 'The Upper reaches of the Chiltern Valleys'.

Ordinary Meeting, 6 *May* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

William James Collins, Augustin Ethelbert Croke, D.D.S.Penn., L.D.S., R.C.S.Eng., Henry Robinson Elsdale, B.A., Kenneth James Evans, Hubert Norris Floyer, John Semple Jackson, B.A., F.G.S., Alan Wilfrid Lane, Mrs. Kathleen Mary Mansfield, Michael Weaver Smith, B.SC., F.R.G.S., and Wilfred Stanley Thurlow, B.SC., A.R.C.S. were elected members of the Association.

The following paper was read: 'Tectonic Styles in the Dalradians and Moines of Parts of the Central Highlands of Scotland', by Basil C. King, D.SC., F.R.S.E., F.G.S., and Nicholas Rast, B.SC., F.G.S.

Ordinary Meeting, 10 *June* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

John Frederick Brewer, Miss Christine B. Glasgow, Ruby Gladys Maria Kafka, Edwin Charles Keen, Anthony Howard Pocock and John James Veevers were elected members of the Association.

The following papers were read: (a) 'The Meta-Sediments of Bunbeg (Co. Donegal), and their Relationship to the Surrounding Granite', by E. H. Timothy Whitten, Ph.D., A.K.C., F.G.S.; (b) 'The Carboniferous Basement Series of the Cross Fell Area, Cumberland and Westmorland', by J. G. Capewell, B.SC., Ph.D., F.G.S.

Ordinary Meeting, 1 *July* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

Clive Oswald Adams, Lloyd McIntosh Adams, Rex Barham, B.SC., Ronald Percival Bengry, M.SC., Robin Alan Broom, B.SC., Walter Butz, B.A. (Wisconsin), Dewi Aelwyn Bryn Davies, B.SC., Ph.D., John Frederick Dewey, Kemal Erguvanli, Anthony Ewart, Alastair Donald Fraser, Peter Ibbotson, Robert Francis Innes, B.SC., A.R.I.C., Dip. Agric. (Cantab.), A.I.C.T.A., Winston Leonard Jackson, Robert Langley, Charles Bernard Lewis, B.A., Barron Reginald George McGrath, Norman Washington Manley, Richard Stanley Marriner, William Frederick Nenninger, George Richardson Proctor, B.A., Roger Charles Sansom, Michael Benjamin Cunningham Scott, Ann Sparrow, Stanley Arthur Goodwin Taylor, Harry Edwin Vendryes, J.P., F.R.M.S., Howard Raymond Versey, B.SC., Stanislaw Aleksander Vincenz, Ph.D., B.SC., A.R.C.S., D.I.C., F.R.A.S., Bernard Theodore Vine, M.A., and Verners Aleksandrs Zans, F.G.S. were elected members of the Association.

The following paper was read: 'Ancient Strands on Lundy, in relation to those of Devon, Cornwall and South Wales', by A. J. Dollar, B.SC., Ph.D., A.K.C., F.R.S.E., F.G.S.

Ordinary Meeting, 5 *November* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

John Michael Adams, B.SC., Donald Clive Armsworth, Armaund Munoz-Bennett, Mrs. Gillian Ida Cook, Araphael Charles Cotterell, Richard Benjamin Croft, Leila Dutt, B.SC., Eric Lawson Frater, B.SC., James Austin Hartman, B.S., M.S., Mrs. Grace Havergal Isaacs, Horace Alexander Lake, James William Lee, M.A.SC., Ph.D., Margaret Longstaff, B.SC., Althea Macpherson, Henry James Northcott, John William Hamilton O'Regan, M.A., Leaford Alexander Patrick, James Douglas Peacock, B.SC., Bertram Arthur Owen Randall, B.SC., Keith Everard Gayle Taylor, B.SC., and Arthur Frederick Thelwell were elected members of the Association.

The Reunion, which followed, was held in the Large Hall, Chelsea Polytechnic. (For list of exhibits, see page 188.)

Ordinary Meeting, 2 *December* 1955. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

John Christian Andersen, Basil Vernon Bailey, Charles H. Blake, Douglas Frank Blanks, Phillip Donovan Reece Bovell, John Bernard Bronn, Joyce Constance Brown, B.SC., Harold Keith Burke, Kenneth C. Cannicle, Margaret R. Carson, B.A., Julian Prosser Chanter, Keith Chaperlin, Leonard Roy Clemetson, Kenneth Coe, B.SC., F.G.S., William Spratt Cole, Jnr., David Lawrence Cooke, Melvin George Cunningham, Kathleen Oriel Cusack, B.SC., William Rees Davies, Nicholas Edwards, Alton Caveril Ellington, M.SC., Ph.D., James Reginald Elliott, David Emlyn Evans, B.A., Orlando Felix Ferreira, Patrick Vincent Glody, Walter Wyatt Grave, M.A., Ph.D., LL.D., James Frederick Gore, G. E. Griffith, Gerald Vincent Helwig, B.SC., Ph.D., Vincent George Hill, M.S., Dennis Edward Jackson, B.SC., Henry Edwin James, B.A., B.SC., F.R.G.S., Charles William Jarratt, Margaret Elizabeth Johnson, B.SC., Norman Kirby, B.SC., F.R.I.C., Charles Wilfrid Knight, M.SC., Merton William Lallman, B.S., Leslie Virginia Long (Mrs.), B.S., M.A., Rudolph Stanislaus Lungrin, Georg Moore-Lewy, B.SC., Norman Philip Morgan, Alexander Graham Neill, Oliver Augustine Norris, James Ferguson Parker, Robert John Parsons, Roland Parsons, B.A., Donald Stuart Paterson, Peter John Perkins, Owen Ransford Haig Pitter, John Francois Potter, Donald Richard Reeves, Edmund Gerard Rickman, A.R.I.C.S.(Eng.), C.L.S., Jean Alana Robinson (Miss), Nerissa Eugenie Ross (Mrs.), Rheta Olivine Stewart, Brian Albert Sturt, B.SC., James Henry Sykes, Cyril Sommerville Tighe, Alan Francis Tullett, Garth Leon Underwood, B.SC., Jia Lal Varma, M.B., B.S., Wilfrid Foulston Vernon, Edwin John Waddon, George Charles Walrond, Ronald Sidney Waters, M.A., May Evelyn Webb, B.LITT., M.A., and Hilda Wildman were elected members of the Association.

The following paper was read: 'The Dislocated South-Western Margin of the Insch Igneous Mass, Aberdeenshire', by Professor H. H. Read, D.SC., F.R.S., F.G.S.

LIST OF EXHIBITS

British Museum (Natural History), Department of Geology

(*a*) The earliest Australian fishes: a new collection from the Middle Devonian of New South Wales. H. A. Toombs.
(*b*) An armoured dinosaur recently collected from the Lower Lias of Lyme Regis, Dorset.
(*c*) Some new specimens of the rare Downtonian ostracoderm *Corvaspis kingi*. A. S. Woodward.
(*d*) A fine specimen of *Lepidotes elvensis* (Blainv.) recently collected from the Upper Lias of Rutland.
(*e*) The new Swanscombe skull bone. B. O. Wymer, J. Wymer and K. P. Oakley.

Geological Survey and Museum

(*a*) Specimens from Rockall.
(*b*) Recent maps and Publications.
(*c*) Ashton Park Borehole, Bristol.

Chelsea Polytechnic, Department of Geology

Exhibit of recent work by members of the Department.

Ackermann, K. J.

Some rock types from the area studied by the University College, London, Research team in Northern Norway.

Anthony, Dr. H. D.

Photographs taken during the Seaton Field Meeting, August 1955.

Barron, R. S. (Dauntsey's School)

The Geology of Pewsey Vale.

Best, C.

Photographs taken during the Seaton Field Meeting, August 1955.

Bottley, Mr. and Mrs. E. P.

(*a*) Minerals collected on Elba during 1955.
(*b*) Crystals of morganite and associated beryls from Minaes Geraes recently collected.

(*c*) Some fine old mineral collection specimens.
(*d*) The Teachers' Projection Petrological Microscope. A new microscope projector which is specially devised for teaching the way to use and how to recognise minerals in thin section with a Petrological Microscope.

Carreck, J. N. and M. P. Kerney

(*a*) Material to illustrate the sequence of faunas of small mammals in Pleistocene and Holocene deposits.
(*b*) Remains of Pleistocene Mammalia from the Medway Valley.

Collins, J.

A Selection of Decapod and Cirripede Crustacea.

Cox, Dr. L. R.

Documents and photographs relating to the inauguration of the Jamaica Group.

Curry, D. and F. C. Stinton

A London Clay Fauna from Holt Wood Brickyard, near Wimborne, Dorset.

Cutrock Engineering Co. Ltd.

(*a*) 'Minnicutta' Rock Cutting Machine.
(*b*) Stereometers.
Clinometers.
Contact Goniometer.
Integrating Micrometer.
(c) Geological hammers and augers.
(*d*) Diamond Wheel Lapping Unit.

Davis, A. G. and M. P. Kerney

Pleistocene Non-Marine Mollusca from Swanscombe, Kent.

Dollar, Dr. A. J.

(*a*) Erratics from the Isles of Scilly.
(*b*) Dreikanter from Jan Mayen Island, Greenland Sea.
(*c*) Chalcedony from the Deccan Traps, Kalyan, India.
(*d*) A New Geological Clinometer.

Eastwood, T.

Film on Exploratory Boring.

Goodchild, J. H.

Brockram from Combe Martin Cliffs.

Hayward, Dr. J. F.

(*a*) Geological Field Meetings and the Youth Hostels Movement.
(*b*) Natural Flakes and Artefacts from the Essex coast.
(*c*) Black-coned, zoned flints associated with the Clacton flint industry and a possible source.

Hester, S. W.

Specimens of nodular calcareous sandstone from the Reading Sands of Harefield, Middlesex.

Martin, E. R.

A method of storing small fossils compactly yet with ease of access.

Milbourne, R. A.

Ammonites from the Lower Gault of West Kent.

North, Dr. F. J.

Examples of exhibits and cases of specimens circulated to Schools by the National Museum of Wales.

Price, D. and D. J. Shearman

Ripple marks in Sandstone from the Yoredale Series, near Hawes.

Staff and Students—Geology Section, Kingston Technical College

Specimens from Shropshire and Girvan.

Stebbing, W. P. D.

Fossils collected at past Field Meetings.

Venables, E. M. and D. Curry

Bracklesham fossils from Selsey, Sussex.

Wilkinson, Miss H. P.

Eocene fruits and seeds from Sheppey and Herne Bay.

Williams, Prof. David

Ore specimens from tungsten, iron and arsenic mines in Sweden, collected during July 1955.

Wilson, Dr. Gilbert

(*a*) A demonstration pressure-box, to illustrate the formation of simple geological structures.

(*b*) A model of a cylindrical fold illustrating a method of constructing a fold-profile.

(*c*) Some glacial erratics from the drift around Ampleforth, North Yorkshire.

Wright, C. W.

(*a*) Homoeomorphy in Cretaceous Ammonites.

(*b*) New and interesting Cretaceous Fossils.

FIELD MEETINGS 1955

The following field meetings and demonstrations took place:

19 *February*. Demonstration at the Photogrammetric Laboratory of the Department of Civil Engineering, University College, London, at the invitation of Prof. E. H. Thompson.

5 *March*. Visit to the Department of Geology, King's College, London, at the invitation of Prof. J. H. Taylor, A.M., Ph.D., M.I.M.M., F.G.S.

2 *April*. Demonstration at the Central Laboratory, G. Wimpey & Co., Ltd., Southall, Middlesex.

8–11 *April*. Easter Field Meeting in the Settle District. Directors, Miss M. M. Sweeting, M.A., Ph.D., and W. W. Black, B.SC., Ph.D., F.G.S.

17 *April*. Field Meeting in the North Chilterns and Aylesbury District. Directors, A. Morley Davies, D.SC., A.R.C.S., F.G.S., and Vernon Wilson, Ph.D., A.M.I.M.M., F.G.S.

8 *May*. Field Meeting at Northfleet and Snodland. Director, Major J. P. T. Burchell, M.C., F.S.A.

21 *May*. Field Meeting at Charlton and Bostall Heath. Director, F. J. Epps, F.G.S.

28 *May*–1 *June*. Whitsun Field Meeting in North Devon. Directors, D. J. Shearman, B.SC., F.G.S., assisted by R. Goldring, B.SC., F.G.S., and A. J. Dollar, Ph.D., A.K.C., F.R.S.E., F.G.S., assisted by F. J. Fitch, B.SC., F.G.S.

3–4 *June*. Week-end Field Meeting in the Central Cotswolds. Director, D. V. Ager, Ph.D., F.G.S.

18 *June*. Field Meeting at Mount's Wood, Greenhithe and Swanscombe Hill. Director, S. A. J. Pocock, B.SC., F.G.S.

10 *July*. Field Meeting to study the Wealden and Purbeck of Sussex. Directors, Prof. P. Allen, M.A., Ph.D., F.G.S., and F. Howitt, B.SC., F.G.S.

24 *July*. Field Meeting at Danbury Hill, Chelmsford. Director, K. M. Clayton, M.SC.

7 *August*. Field Meeting to study the Great Oolite Series of Oxfordshire. Director, W. S. McKerrow, M.A., D.Phil., F.G.S.

20–27 August. Summer Field Meeting (i) The Mesozoic Rocks of the South Devon and Dorset Coasts. Director, W. E. Smith, M.SC., F.G.S., assisted by D. V. Ager, Ph.D., F.G.S., and D. J. Shearman, B.SC., F.G.S.

21 *August*. Field Meeting in the Canterbury district. Director, J. G. O. Smart, B.SC., F.G.S.

3 *September*. Field Meeting at Aylesford. Director, J. N. Carreck, F.G.S.

10 *September*. Field Meeting at Kettering. Director, E. Cohen, M.SC., F.G.S.

18–28 *September*. Summer Field Meeting (ii) in Anglesey and Snowdonia. Director, Prof. R. M. Shackleton, Ph.D., F.G.S., assisted by Prof. F. W. Cope, D.SC., F.G.S., and J. C. Harper, Ph.D., F.G.S.

24 *September*. Field Meeting at Guildford. Director, B. Ainsley, F.G.S.

8–9 *October*. Week-end Field Meeting in the Thaxted District. Director, J. F. Hayward, Ph.D., F.G.S., assisted by B. W. Sparks, M.A., F.G.S.

26 *November*. Demonstration at the new Geochemical and Geophysical Laboratories, Imperial College of Science and Technology, London, at the invitation of Prof. D. Williams, D.SC., Ph.D., B.Eng., F.G.S.

NORTH-EAST LANCASHIRE GROUP

The following meetings and field meetings were held:

21 *January*. Lecture: 'The Post-Glacial Geology of South-West Lancashire', by R. K. Gresswell, M.A., F.R.S.A., F.R.G.S., F.G.S.

18 *February*. Lecture: 'The Middle Coal Measures of the Burnley Coal Basin', by G. T. Roberts, B.SC., F.G.S.

25 *March*. Chairman's Address: 'The Permian Succession of the Durham Coast', by J. Ranson, A.M.I.Min.E., F.G.S.

23 *April*. Field Meeting: 'Whalley District', directed by D. H. Learoyd, B.SC., F.G.S.

17 *May*. Field Meeting: 'Cliviger Gorge' (joint meeting with the Yorkshire Geological Society), directed by I. A. Williamson, F.G.S.

18 *June*. Field Meeting: 'Rochdale District', directed by J. Ranson, A.M.I.Min.E., F.G.S.

20 *August*. Field Meeting: 'Wheelton District, near Chorley', directed by G. F. Urry.

10 *September*. Field Meeting: 'Bolton Abbey District', directed by H. C. Versey, D.SC., F.G.S.

14 *October*. Annual General Meeting.

18 *November*. Lectures: 'Heavy Mineral Analysis', by E. Proctor; 'Underground Waters of Malham', by N. Thompson; 'A Student's Aspect of Crummock Dale', by M. Thornton.

16 *December*. Lecture: 'The Scenery and Geology of Britain's Mountains', by I. A. Williamson, F.G.S.

MIDLAND GROUP

The following meetings and field meetings were held:

22 *January*. Lecture: 'Some aspects of the geology of St. Jonsfjord, West Spitsbergen', by P. A. Garrett, B.SC., F.G.S.

26 *February*. Lecture: 'Geologists' Association Reminiscences', by Miss Grace M. Bauer.

16 *April*. Field Meeting: 'Wrens Nest, Dudley', directed by A. Ludford, M.SC., F.G.S.

6–8 *May*. Field Meeting: 'Matlock', directed by D. Parkinson, D.SC., F.G.S., and A. Ludford, M.SC., F.G.S.

4 *June*. Field Meeting: 'Pouk Hill, Walsall', directed by A. Ludford, M.SC., F.G.S.

9 *July*. Field Meeting: 'The Onny River', directed by I. Strachan, Ph.D., F.G.S.

15 *October*. Lecture: 'Shoreline development in England and Wales', by A. Ludford, M.SC., F.G.S.

12 *November*. Lecture: 'Random thoughts on some uses for fossils', by C. J. Stubblefield, D.SC., F.R.S.

10 *December*. Exhibition of coloured slides and Christmas Party.

NORTH STAFFORDSHIRE GROUP

The following meetings and field meetings were held:

13 *January*. Lecture: 'Derbyshire Lead Mines', by Miss Nellie Kirkham.

11 *February*. Lecture: 'New Light on Early Man', by K. P. Oakley, Ph.D., B.SC., F.S.A.

10 *March*. Annual General Meeting: Address by Retiring Chairman, J. C. Parrack, B.SC., F.R.G.S.

12 *May*. Lecture: 'Coal and Oil Shales', by Prof. L. R. Moore, D.SC., Ph.D., F.G.S.

27–30 *May*. Field Meeting: 'Whitby District', directed by J. C. Parrack, B.SC., F.R.G.S.

17 *July*. Field Meeting: 'The Onny River', directed by J. T. Wattison, F.G.S.

13 *October*. Annual Conversazione.

10 *November*. Lecture: 'Potholing' (illustrated by a film), by A. B. Malkin.

8 *December*. Lecture: 'Geological problems in Coal Mining', by E. Steele, M.I.M.E., of the National Coal Board.

JAMAICA GROUP

The following meetings were held:

7 *October*. Inaugural Meeting. Election of officers and committee and discussion of future programme. The meeting was followed by a Dinner.

27 *November*. Field Meeting: 'A traverse through the Port Royal Mountains', directed by V. A. Zans, and 'An examination of the Blade-Orchard iron ore deposit', directed by A. D. Fraser.

DONATIONS TO THE LIBRARY

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————. 1955. Blue John fluorspar. *Proc. Yorks. geol. (polyt.) Soc.*, **30,** 35–60.

————. 1955. The Upper Carboniferous rocks of the Stainmore Coalfield. *Geol. Mag.*, **92,** 218–30.

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HALLAM, A. 1954. The Lincolnshire limestone of Nevill Holt, Leicestershire. *Trans. Leicester lit. phil. Soc.*, **48,** 1–8.

HARPUM, J. R. 1954. Formation of epidote in Tanganyika. *Bull. geol. Soc. Amer.*, **65,** 1075–92.

HIMUS, G. W. 1954. *A dictionary of geology*. Penguin reference books, R.8. Harmondsworth.

JAANNSSON, V. & I. STRACHAN. 1954. Correlation of the Scandinavian Middle Ordovician with the graptolite succession. *Geol. Fören. Stockh. Förh.*, 684–96.

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MITCHELL, G. H. *et al.* 1954. Supplement to the geology of the Barnsley district. *Mem. geol. Surv. U.K.*

MOORE, R. C. 1954–5. *Treatise on invertebrate paleontology*, parts D, E, G. Geological Society of America. Kansas, U.S.A.

NORTH, F. J. 1955. *The evolution of the Bristol Channel*. National Museum of Wales, Cardiff.

STEVENSON, I. P. *et al.* 1955. Geology of the country between Burton-on-Trent, Rugeley and Uttoxeter. *Mem. geol. Surv. U.K.*

OBITUARY NOTICES, 1955

GEORGE WALTER GRABHAM, O.B.E., died at Khartoum, Sudan, 29 January 1955, at the age of seventy-two, after being a member of the Association for fifteen years.

He was educated at University College School and St. John's College, Cambridge, and in 1903 joined the Scottish Office of H.M. Geological Survey. In 1906 he went to the Anglo-Egyptian Sudan where he served as Government Geologist until 1934 and subsequently as Geological Adviser. Although his birthplace and family home was Madeira, even after his retirement he generally spent part of each winter in the Sudan, where he retained a house.

He had begun his career soon after the reopening of the Sudan and he acted, in a way, as a bridge between the old tribal leaders, who had grown up with him after the Mahdia, and the graduates of Gordon College where he had his office. He was esteemed by all classes. He took great pleasure in introducing younger Sudanese officials to Europe and Britain before such visits were sponsored officially.

He was a bachelor but he was generous in his hospitality at both his homes. In the Sudan, usually his visitors were entertained after dinner by a showing of lantern slides made from his own excellent photographs, and to Madeira wine from his own vines. Many more friends will recall his annual Christmas Card—often a view of some striking geological or scenic feature of that little-known country.

His published works are comparatively few, but much of his labours are recorded in detailed reports on water supply, mineral deposits and irrigation engineering problems. In a period of retrenchment he added to his duties the oversight of the Sudan's antiquities, its Ethnological Museum and the Omdurman Museum of the Mahdia. His constant travelling enabled him to make inspections of the Egyptian Irrigation Department's Nile gauges and meteorological stations. This led him to organise the first upper-air wind observations in the Sudan, for Imperial Airways, with the necessity for devising a method of generating hydrogen and storing rubber balloons under the tropical conditions of Khartoum. The latter were kept successfully down a disused well.

He knew the outlying country—the real wilderness—better than any other single British official, and there was always a friend to be met in the most remote village. Sometimes he would go on leave, or come back, by unorthodox routes, such as crossing to Nigeria in merchants' lorries. When he brought his new 'Baby' Austin to Khartoum, he disembarked it at Massawa, in Eritrea (the Customs Officers at Port Sudan not being sufficiently accommodating), and drove it from there, completing his journey alone over the Butana, a virtually uninhabited waste some 200 miles in length, known in detail to Grabham, however, who had crossed it several times by camel. J.M.E.

DAVID SALUSBURY HAIG was killed in a motor accident in January 1955, at the early age of forty-two. The Association, of which he had been a member since 1948, and all Haig's numerous geological friends, suffered a great blow by this tragedy. His short life was packed with examples of selfless service to his country and his associates.

Haig was educated at Magdalene College School and studied geology under Prof. H. L. Hawkins at Reading University just prior to the last war. A member of a distinguished family, he joined his regiment in 1939, was wounded in the retreat to Dunkirk, was captured, and remained in German prison camps until 1945. In 1947 he returned to Reading University to take an Honours degree in Geology and to carry out research. In 1951 he joined the then Opencast Division of the Ministry of Fuel and Power as geologist, ultimately being placed in charge of the Wrexham Office. He deliberately selected this work in the belief that, during the desperate coal shortage of that time, a geologist had no right to indulge in his own personal preference for research. Thus he put aside his own work for national service, as he had done in 1939.

In his public and private life Haig set his standards high. He worked with meticulous accuracy. His career at Reading was marked by numerous acts of generosity to fellow students who included, at that time, many married ex-service men resuming interrupted studies under financial difficulties of varying degrees of acuteness. He provided accommodation in his large house at Henley-on-Thames and delightful house parties at his country house in Mid-Wales. Gratitude embarrassed him and his integrity was in inverse proportion to his self-effacing modesty. He was married only six weeks before his death. F.H.

PHILIP FRANK HUTCHINS was born on 5 July 1927 at Northampton, where his parents and younger brother live, and where he was an active member of St. Edmund's Church. He was educated at Northampton School in which he became Senior Prefect.

In 1945 he went up to St. John's College, Cambridge, with a Northampton Borough Major Scholarship and soon his interest became centred in geology. This, together with chemistry and physics, constituted the subject for Part I of his Tripos in 1947. Two years later he took Part II in geology, with mineralogy and petrology, and equipped with this knowledge and a grounding in sedimentary petrology, he entered upon a series of investigations which won him successive distinctions. After the Bonney Award of St. John's College in 1949, he was elected an Amy Mary Preston Read Research Scholar of the University of Cambridge in 1950, and a Hutchinson Research Student at St. John's College in 1951. These, together with a D.S.I.R. Research Grant, enabled him to work for the degree of PH.D., which he achieved in 1953.

Philip Hutchins joined Pilkington Brothers Ltd. at St. Helen's as Geologist, and in 1955 joined the geological staff of British Petroleum. It was on one of his first missions in the service of the latter Company that he died in Tanganyika 2 November 1955.

He was a Fellow of the Geological Society of London and of the Royal Geographical Society. He became a member of the Geologists' Association in 1948.

His researches followed two main lines. Arising out of his membership of expeditions to Spitsbergen in 1949 and 1951 he developed a keen interest not only in his petrological investigations there but also in the history of research in that archipelago. In this country his studies related particularly to the petrology of the New Red Sandstone of Devon. In both of these his systematic attention to detail and careful work led to results of importance which were being prepared for publication at the time of his death. His records are models of method which will greatly facilitate the eventual publication of these investigations.

All who knew him will remember his quiet unassuming and thoroughly honest and competent approach, and at first sight one would not suspect the passion for geology which underlay it. He had a deep affection for his College and University where his geological studies developed over a period of eight years. That such work as his should not have come to fruition in his lifetime is a sad loss not only to those who knew him well but also to the geological world as a whole. W.B.H.

MARY SOPHIA JOHNSTON died 23 January 1955. In her, the Association lost a member whose long and zealous services illustrate those of the 'amateur' who finds a vocation in scientific pursuits. She was born at Folkestone on 29 October 1875; her father, the Rev. W. A. Johnston, held the nearby rectory of Acrise, where she spent her early years until, after his death, she and her mother went to live on Wimbledon Hill.

While being privately educated she developed a liking for geology. She became a student at one of the London colleges and joined the Geologists' Association in 1898 from which time she had the interests of the latter very much at heart. She became Illustrations Secretary, generously supported the Illustrations Fund, and maintained the Association's albums of geological photographs in excellent condition, exhibiting them year after year at the Annual Conversazione. Her services, which covered twenty-one years as

Illustrations Secretary (1910–25), Librarian (1932–6), and member of Council, did not end when she no longer held any official position. She was elected an Honorary Member in 1939.

Her private albums of photographs, drawings, autographs, letters from friends, and other personalia illustrated her activities over the greater part of her life. She was one of the first women admitted to Fellowship of the Geological Society of London, and by membership (and in other ways) she aided also the Zoological, Palaeontographical and Royal Geographical Societies. In later life she became Treasurer of the South-Eastern Union of Scientific Societies.

Moving from Wimbledon to a house overlooking Kew Gardens and, later, to one in Cumberland Road, Kew, she continually enlarged her spheres of interest and generous helpfulness. She attended International Geological Congresses in Spain, France, South Africa and the United States of America, and the British Association's meeting in Canada, as well as visiting Egypt and New Zealand. She collected, on all her journeys, many specimens of quartz, chert, opal, chalcedony, agate, geyserite and other forms of silica. Her collections of maps, books, guides, specimens and photographs were consulted by research workers and supplied material for many lantern lectures.

She wrote 'Some Geological Notes on Central France' (*Geol. Mag.*, 1901); 'On a . . . Jurassic Ganoid Fish' (*Ibid.*, 1909); 'On *Labechia rotunda*, a new species of Stromatoporoid, from the Wenlock Limestone. . . .' (*Ibid*, 1915); 'Geological Notes on Spain and Majorca' (*Proc. Liverpool Geol. Soc.*, 1927); 'Note on the Flood Plain, Alluvium and 25-ft. Terrace at Kew, Surrey' (privately printed). In a ten-page paper, published in German, she described certain volcanic phenomena in New Zealand. She compiled also a 'Short History of the South-Eastern Union of Scientific Societies' (1946). Her most important paper, written in collaboration with Miss M. C. Crosfield, 'A Study of Ballstone and the Associated Beds in the Wenlock Limestone of Shropshire' was published in our PROCEEDINGS (1914).

She outlived most of those who were friends and colleagues thirty years ago, but as old links snapped she formed new ones and to the end of her life remained rich in friendships.

As a strongly religious and most sympathetic woman, one not given to wordiness, she expressed her faith by innumerable, kind, generous and often almost secretive benevolences. Her means would have permitted her to lead an easy-going, selfish life; she chose whole-heartedly to follow a very different course, accepting and discharging many responsibilities to aid people and causes in which she had become interested. Her pleasures such as her travels, collecting expeditions, and attendances at scientific gatherings were mostly related to her intellectual interests.

It was my privilege and pleasure to know her for nearly half a century, to value her as a friend, to receive many acts of kindness at her hands, to respect her plain common sense, and to observe over and over again her characteristic trait, which led her to make a ready and practical response when friends or institutions needed help. A.L.L.

GEORGE MARTIN LEES died at the age of fifty-six on 25 January 1955, thus depriving the Association of a personality of high standing in British Geology. He joined the Association in 1924. With his passing, Geology has lost one of its greatest leaders in the economic field, and one who used his great gifts and qualities for the advancement of the science to which he had devoted his life and efforts. We are indebted to his friend and colleague, N. L. Falcon, for a notice of Lees' career and scientific work. (*Proc. Geol. Soc. Lond.*, **1529**, 1955.) Here we find recorded his progress, at the age of seventeen, from St. Andrew's College, Dublin, to the Royal Military Academy at Woolwich; thence, with the Royal Artillery, to France, where he won the Military Cross, and later, with the Royal Air Force, to Egypt and Mesopotamia, where he was awarded the Distinguished Flying Cross. After the 1914–18 war he joined the Civil Administration in Iraq, under Sir Arnold Wilson, and later had the task of reorganising the government of a Kurdistan Sheik. During his travels in these countries his interest in Geology was considerably developed. In 1921 he joined the Anglo Persian Oil Company as a geologist and studied at the Royal School of Mines. He took part in many important surveys in the Middle East and spent a year at the University of Vienna, gaining a PH.D. for his thesis on the Geology of Oman. At the age of thirty-two he was appointed Chief Geologist of his Company (now the British Petroleum Company), holding this post until shortly before his death.

Although much of his work was concerned with the Middle East, British Geology will be increasingly indebted to him for his initiation of planned oil exploration in the United Kingdom. This resulted not only in the discovery of the East Midland oilfields in 1939, but in the recording of an enormous amount of data from deep and shallow boreholes which were put down in the course of the exploration. This work is still in progress, and the geological information now available, and awaiting digestion, will increase enormously our knowledge of British Regional Geology.

Lees was a great gentleman, such as we can least spare. He was beloved by his staff, both senior and junior, and was a personal friend to every member. He was big enough, and found sufficient time, to take an interest in both their private cares, and their successes. To all he was an inspiration.

A.G.D.

EDGAR CHARLES MARTIN died on 24 January 1955, and with his passing the

Association lost an enthusiastic member who had given it devoted service over a long period of years. He was born in Bristol on 3 October 1884. His father, though not a scientist, had strong scientific interests, mainly in astronomy, microscopy and meteorology.

Martin was educated at the Merchant Venturers' School and the Merchant Venturers' Technical College—now a part of Bristol University. He matriculated with honours in 1901 and passed the London Intermediate B.SC. in the same year. In October 1903, when only nineteen years of age, he obtained second class honours in chemistry in the London B.SC. external examination. In 1904 he passed the examination for the Associateship of the Institute of Chemistry. After a year with a commercial firm in Birmingham he spent twelve months at Birmingham University, attached to the King Edward Grammar School for teacher-training, and obtained the Cambridge Teacher's Diploma.

He taught for a year at Tiverton, Devonshire, and during this period he took up original work in geology, which resulted in the publication of two papers in the *Geological Magazine*, i.e. 'New Red Gravels of the Tiverton District'—1908, and 'Probable Source of Limestone Pebbles in Bunter Conglomerate of West Somerset'—1909. These papers are the first record of his geological interests but it is not possible to establish exactly how the latter developed. The only clues we have are the scientific interests of his father, studies of fossils from the Carboniferous Limestone in the Bristol Museum which he recognised in the Bunter pebbles, and some contacts with the late J. W. Tutcher. These publications led to correspondence with Ussher and with Jukes-Brown. He never met either of these geologists but the latter introduced him to the Geologists' Association, which he joined in 1910.

In 1908 Martin obtained first place in the Patent Office examination and was appointed to that Office on 4 February 1908 as an Assistant Examiner, thus commencing his long and distinguished career in the Civil Service. He was promoted to Examiner rank in 1925, and to Senior (later known as Principal) rank in 1925, becoming Adjutant to the Assistant Comptroller in 1943. His services to the Patent Office were recognised by the award of an O.B.E. in 1946. It is stated by a former colleague that, although primarily a chemist, Martin's wide range of knowledge enabled him to cope quite successfully with electrical engineering subjects for many years, until the increasing volume of chemical work finally claimed him. The Patent Office includes a court for trying certain legal issues, such as opposition to the grant of a patent. Martin's appointment as Adjutant empowered him to preside at such hearings, at which it is customary for counsel to be briefed for the two parties to the action. After his retirement in 1950, he sometimes spoke privately of the interest and gratification he experienced in being called upon to preside over such courts.

In Martin's early days in London he lived at Loughton and later at Woodford. In those years he became well acquainted with the natural history of Epping Forest and, characteristically, about 1913, he made a detailed photographic study of the meanderings of the Loughton Brook. In 1923 he moved to Welwyn Garden City and here again he acquired an intimate knowledge of the geology of that district, as displayed when an excursion of the Geologists' Association was held in that area. In 1929 he moved to Worthing where he lived for the rest of his life.

During the long period of twenty-six years at Worthing, Martin gained an intimate knowledge of the geology, geomorphology and archaeology of the South Downs and of the coastal plain of Sussex. Two of his papers, published in the PROCEEDINGS, show the scope of this work, the first, in 1932, on the 'Chalk Zones in the Foreshore between Worthing and Felpham, Sussex', and the second, in 1938, on 'The Littlehampton and Portsdown Chalk Inliers and their Relation to the Raised Beaches of West Sussex'. The maps in these papers show the difficulties of the investigations because they include both heavily built-up areas and foreshore exposures only available occasionally. Thus the details accumulated and the zone fossils collected were recorded over many years from temporary sections, building sites and on foreshore work dependent on low-water spring tides and the chance shifting of beach materials by storms.

In addition Martin led many geological excursions both for the Association and for local societies. Many of these included Highdown Hill and a traverse northward of the South Downs. Typically an excursion would cover the zones of the Chalk, the remnants of Eocene Beds, the Pleistocene deposits, the land forms of the Downs and informed references to any archaeological sites and the architecture of ancient churches passed *en route*. On controversial matters such as the geomorphology, Martin would recount impartially the different opinions, restricting his own comments to the facts verifiable in the field.

Martin served on the Council of the Association from 1934 to 1953 with only one year's break in 1951. He was the Honorary Treasurer from 1935 to 1948 and Vice-President 1949–50. His gifts of caution and extreme carefulness in all detail made him an ideal treasurer and he served in this arduous office for an exceptionaly long period. Moreover it entailed service on many committees throughout the years and these he attended most conscientiously. He was also a Trustee of the Association. His services were acknowledged by the Foulerton Award in 1952, a notable occasion for his family because at the same meeting his son-in-law, Dr. K. P. Oakley, received the Stopes Medal.

Martin was elected a Fellow of the Geological Society of London in 1936 and he attended regularly its meetings. In 1949 the Council of the Society awarded him the Wollaston Fund and on its presentation the

President cited his geological work in Devonshire and Sussex and his long Treasurership of the Association. He was a member of the Worthing Archaeological Society for nearly twenty-five years and served as its President for one year—1940–1. His Presidential Address was on 'The Great Ice Age and its effects in Sussex'. He was also a member of the Worthing Branch of the Geographical Association. From time to time he gave lectures and conducted excursions for a number of local societies.

Another of Martin's interests was historical architecture, especially that of churches, castles and country houses. Like most geologists he was a lover of the countryside and he appreciated greatly holidays amid mountain and moorland scenery. He had a discriminating taste in literature and read fairly widely in history.

It is not easy to do justice to Martin's character because his retiring, almost shy, nature tended to keep his outstanding qualities in the background. The excellence of his work in the Civil Service, his services to scientific societies (particularly our own) and his geological research have been recorded but, with his powers of concentration and remarkable memory, his geological publications might have been more numerous but for his diffidence. The kindest of men, it was his response to any appeal for assistance that revealed his capabilities. On Council, or in a discussion, he had to make an effort to contribute, but when called upon his advice, by reason of his sound judgment, carried great weight. Always quiet in speech and action, his life was an example of kindly service to his fellows and of accomplishment in his scientific pursuits. He is survived by his widow, his son and daughter, Mrs. K. P. Oakley.

Martin's considerable collections of fossils and other specimens, all most carefully numbered and catalogued, have been found permanent homes for future use. A selection of Chalk polyzoa has been presented to the British Museum (Natural History); the excellent collection of other fossils from the Chalk of the Worthing District has been placed in the Worthing Museum and the general collection has been presented to University College, Exeter.

E.E.S.B.

EDWARD AMBROSE OLIVER, A.M.I.C.E., A.M.I.Struct.E., spent the early part of his career as an Assistant Mining Surveyor in the South Wales coalfield. He was a member of the Association from 1948 until his death in 1955.

In 1925 he joined the Office of Works as a Civil Engineering Assistant and at the time of his decease was a Senior Civil Engineer in the Ministry of Works. During the last half decade he was in charge of the Ministry's Soil Mechanics Laboratory.

He served as an Assessor on the Road Research Board of the D.S.I.R. and was a member of the Inter-departmental Committee which produced a special report on 'The Effects of Mining Subsidence on Small Houses'.

R.F.G.

STANLEY SMITH was born at Middlesbrough on 7 March 1883. On leaving Darlington Grammar School he worked for a few years in the chemical laboratory of the Darlington Forge Co., acquiring there a knowledge with which he frequently surprised listeners in later years. He entered Armstrong (now King's) College, Newcastle-on-Tyne, in 1904, and after graduating in 1907 and taking his M.SC. degree in 1909, he went, by means of a Fellowship of Armstrong College, to Clare College, Cambridge, where he graduated in 1912. He took his D.SC.(Dunelm) in 1915, and joined the staff of the University of Bristol in 1922, retiring as Reader in Palaeontology in 1948.

It was Professor G. A. Lebour who urged Stanley Smith to investigate the coalfields of Northumberland and the Carboniferous Limestone of the fells, and so set his feet on the path of what became his life's dominant research. For Stanley Smith soon discovered the need for a complete revision of the Carboniferous coral genera on which he embarked, encouraged by Dr. Arthur Vaughan and Dr. W. D. Lang. Quickly he realised that an even more fundamental revision was required—that of the Palaeozoic coral genera as a whole. It was a formidable task, too great for a single lifetime, but he brought to it a steady persistence, an absorbing interest in the Palaeozoic corals and their literature, a wonderfully retentive memory for them, and a capacity for detailed work which often seemed inexhaustible. These, together with his careful observations and his continued insistence that any such revision must be based on a critical examination of type-specimens and type-material, made his coral work most valuable, and justly earned for him his world-wide reputation. From 1913 much of this work was carried out in connection with the British Museum (Natural History) where he collaborated later with Dr. W. D. Lang in making important contributions to palaeontology, including the enunciation and development of the concept of genomorphs.

But Stanley Smith's interests were not confined to Palaeozoic corals, nor even to palaeontology. Thus, *inter alia*, his first two papers were on the Cleveland Dyke and the Grainsgill Greisen respectively; he contributed an important Geological Survey Memoir on the lead and zinc ores of Northumberland and Alston Moor; he discovered an unsuspected area of Tremadoc Shales in the Tortworth inlier of Gloucestershire; and he collaborated with Mr. D. E. Eichholz, of the University of Bristol, in a new translation of the classic treatise by Theophrastus. His work was recognised by the Geological Society of London through its award to him of the Lyell Medal in 1947.

It was due to Stanley Smith's initiative that the Association's Easter Field Meeting of 1934 was held in the Gloucester district. He seized upon a casual remark of mine, one evening, and produced overnight a draft programme which was accepted with only slight modification.

This willingness always to help others was typical of Stanley Smith. Behind his shyness, modesty and humility lay a warm charity and a penetrating ability to estimate people and events that was tempered by a kindly, gentle humour.

In his last few years, Stanley Smith suffered much pain from an affliction of his back, but still he gave himself to his researches, almost to the end. He died after a heart attack on 1 July 1955. H.D.T.

HUBERT MAITLAND TURNBULL, who died on 29 September 1955, at the London Hospital, joined the Association in 1919. Born in Glasgow in 1875, he was educated at Charterhouse and Magdalen College, Oxford, where he took Greats and played Soccer for Oxford. Then he entered the Oxford medical school and later proceeded to the London Hospital where he qualified in 1902. Two years later, with a Radcliffe Travelling Fellowship, he went abroad and studied at Dresden. On returning he worked for his D.M. at the Pathological Institute of the London Hospital and in 1906 became the Director. There he built up a personal reputation that made him an authority in special pathology. He retired from the institute, which had become the Bernhard Baron Institute in 1927, and was made honorary consultant morbid anatomist to the London Hospital, and Emeritus Professor of Anatomy in the University of London. In 1939 he was elected a Fellow of the Royal Society, and to mark his retirement, the University of Oxford conferred upon him the honorary degree of Doctor of Science. Apart from his professional work, his interests and hobbies lay out of doors—in gardening, bird watching, and geology in the field. He was also a golfer and fisherman. A fuller notice appears in the *Lancet* of 8 October 1955. F.H.M.

JOHN THEODORE HEWITT was born at Windsor on 12 October 1868 and received his early education at the Hartley Institute, Southampton. In 1884 he won a National Scholarship and proceeded to the Normal School of Science (later called the Royal College of Science) where he studied principally chemistry, physics and mechanics and, in 1886, geology under Prof. Judd. In December of that year he sat for, and was awarded, a scholarship at St. John's College, Cambridge. In January 1887 he passed London Matriculation and in June 1887 the Associateship of the Normal

School of Science. He went up to Cambridge in October 1887, and in 1889 passed Part I in chemistry, physics, geology and botany. He attended Prof. J. E. Marr's Part II geology lectures. In 1889 he also took the London Intermediate Science Examination and secured a chemistry exhibition, a physics exhibition and a Neil Arnott medal. Continuing at Cambridge he was awarded a First Class in Part II of the Tripos in 1890, with chemistry as the principal subject and physics as 'subsidiary'. Later in the year he obtained a First Class in the London B.SC. degree and was once more awarded a scholarship on merit. He worked for a time at the Universities of Heidelberg and Berlin, interspersed with periods at Cambridge. He took and passed the examination for PH.D. (Heidelberg) in January 1893 and in June of the same year obtained the degree of D.SC. London.

Hewitt was elected to a 'Professorship' of Chemistry at the People's Palace Technical College and started work there in 1894.

In 1910 Hewitt was elected a Fellow of the Royal Society.

When East London College became a School of the University, in 1915, Hewitt was made a University Professor. When the College was re-named Queen Mary College, in 1934, Hewitt became one of its first Fellows. After the first world war, during which Hewitt received a commission as 'Major, General List, attached Royal Engineers', he resigned his professorship, went into industrial chemistry, and after 1924 carried out consulting work.

Although Hewitt's main activities were in the chemical field, he remained interested in geology for many years. He was a member of the Association from 1898 until his death in 1954. A fuller notice appears in *Biographical Memoirs of Fellows of the Royal Society*, Volume 1, November 1955.

F.H.M.

HAROLD J. OSBORNE WHITE, who died on 3 June 1954, at Deal, was a member of the Association for sixty-three years, although the present generation saw him but rarely. In the early decades of this century scarcely a year passed without an excursion of which he was the director, and he contributed not a little to the PROCEEDINGS. During the period of his greatest activity he was closely associated with the late Ll. Treacher—for many years they lived only about two miles apart—and their joint work (published by the Geological Society of London) gave an impetus to zonal study of the inland exposures of the Chalk which was comparable with that produced by A. W. Rowe in his studies of the coastal sections. Osborne White's profound knowledge of the Chalk of southern England led to a commission to compile the sheet memoirs for those maps of H.M. Geological Survey which cover the Cretaceous areas. These memoirs, packed with information and lucidly written, are an abiding record of his activities. During the time when these were being produced he was living at Wargrave, whence he later moved to Brading. While there he produced the *Short Account of the*

Geology of the Isle of Wight, which is the largest and best known of his publications. In addition to his stratigraphical work, he took great interest in problems of geomorphology—especially in the matter of river-development. A few years ago he moved to Deal, in failing health, and survived to become a Senior Fellow of the Geological Society of London, though for a few months only. He was of a shy and retiring temperament, and although his urbanity gained him many friendly acquaintances, there were few who could claim intimate knowledge of him, and of these most have preceded him as subjects of obituary notices. H.L.N.

SIMEON PRIEST died 16 October 1954, at the age of seventy-eight, when the Association lost a senior member, known in Staffordshire before 1902, and later in Kent, as an active local geologist.

Priest was born at Woolaston, a hamlet of Stourbridge, near Kidderminster, in 1876. As a young man he studied science, in addition to training for the teaching profession. His appointments included those of Science Demonstrator at Longton High School, Staffordshire, and the Sutherland Technical Institute. He carried out much field work in Staffordshire and nearby, and his search for fossil arthropods is acknowledged in two Monographs of the Palaeontographical Society, i.e. Bolton's *Fossil Insects of the British Coal Measures* (1921–2) and Pocock's *Terrestrial Carboniferous Arachnida of Great Britain* (1911). In the latter a new species, *Anthramartus priesti*, is named after him.

His wide interests were shown by his familiarity with industries around Stourbridge, and the hours spent by him at night in glass works and iron foundries. He was much associated with the North Staffordshire Archaeological and Naturalists' Field Club and the Lancashire and Cheshire Fauna Survey.

From 1902 to 1907 he lived in Hertfordshire, where he studied the Chalk and Pleistocene gravels. In the latter year he was elected a Fellow of the Geological Society of London, having been proposed by John Ward of Longton, Wheelton Hind and A. J. Jukes-Browne, and also joined our Association.

In 1907 Priest entered the Kent education service, teaching at schools near Dartford until his retirement, owing to ill-health, in the early 1930's. From 1907 onwards he pursued with avidity his studies in geology, archaeology, and botany, then living at Horn's Cross, near Dartford. He was a founder member of the now extinct Dartford Naturalists' Field Club, reporting in its *Transactions* on such subjects as Recent myriapoda, including little-known luminous centipedes and millipedes. He also helped to found the still surviving Dartford District Antiquarian Society.

Priest was long and closely concerned with the Geology Department of

Chelsea Polytechnic, and was elected Vice-President of its Geological Field Club in 1911, President in the following year, and Honorary Member in 1930. He led parties of its members to many Kentish geological sites.

In 1919 he became a member of the Dartford Library and Museum Committee, and Vice-Chairman in 1923, having helped to found the Dartford Borough Museum a year after his arrival in Kent, and long assisted with identification of museum acquisitions. In 1934 he was appointed Curator, and held this post until his death, although finally obliged by illness to relinquish much of the work. As Curator, Priest became well known in Dartford, and his knowledge was frequently sought. He was President of the Plumstead and District Natural History Society from 1929–30, Lecturer at the Woolwich Borough Museum at one period, and carried out much work for the Woolwich Historical and Scientific Society.

As a member of our Association he frequently exhibited at annual conversaziones, and directed many field meetings in Kent, and once to Stevenage, Herts, between 1908 and 1935. His long series of publications in our PROCEEDINGS was mainly in the form of reports of field meetings, but other papers are to be found in the *Proceedings* of the South-Eastern Union of Scientific Societies, of whose Geological Section he was Honorary Secretary; the *Transactions* of the Dartford Antiquarian Society, and a Kent journal, the *Invicta Magazine*. Part of his archaeological and historical work was made available to other investigators for publication, and is to be found in a number of books and papers. He received the Foulerton Award of our Association in 1926. He made a protracted study of the Kentish Lower Eocene, some results of which were used by Prof. L. D. Stamp and the late Dr. H. A. Baker in their published papers. Some of his publications were issued jointly with these workers. He studied all other formations in his district, and many references to his work appear in the Dartford Memoir of H.M. Geological Survey. His assiduous collecting from the Blackheath Beds at Lessness Woods, near Plumstead, is acknowledged in Dr. E. I. White's *Vertebrate Faunas of the English Eocene*, issued by the British Museum (Natural History) in 1931.

For the Dartford Antiquarian Society Priest investigated the Roman site at North Ash in 1914, the Iron Age site in Stone Wood brickfield four years later, and the Norman manor house of Luddesdown Court about 1918. In 1925 he supervised excavation of the Roman site at Farningham, which he described in the Society's *Transactions* in 1931. During 1937 and 1938 he helped to excavate the Horton Kirby Saxon cemetery, an account of which was issued by the Society in 1938. He rescued all available pottery from the Iron Age village site at Crayford, described by Prof. Ward Perkins in the Prehistoric Society's *Proceedings* for 1938. His work on the Belgic site at Hulbury, near Lullingstone, was unfortunately not published. In his hands the archaeological material in the Dartford Museum became one of the finest small series of Palaeolithic, Iron Age, Roman, and Saxon objects in the provinces.

In the words of the Borough Librarian of Dartford, Priest's death has deprived the town of a man of scholarly intellect and great kindness. Priest's other outstanding characteristic was his enthusiasm for encouraging young people to take up the study of the field sciences. He leaves two sisters, still living in the district. J.N.C.

British Palaeontology: A Retrospect and Survey

by L. R. COX, F.R.S.

Presidential Address delivered 4 March 1955

IN A PRESIDENTIAL ADDRESS it is usual for a palaeontologist to re-examine one of the more general problems which exercise his mind—the species concept, the operation and laws of evolution, and the scientific basis for the dating of rocks by fossils. In fact, such subjects have been very ably discussed by others in fairly recent addresses elsewhere. For this reason I propose to avoid theoretical discussions in this address and to review the evolution, not of any fossil group, but of British palaeontology itself. I realise fully that the progress of palaeontology in this country should be considered more properly in relation to that of work and ideas elsewhere, for until a few years ago there was free communication, and usually co-operation, between workers everywhere. Also it must be made clear that nobody could claim that the study of fossils began in this country. However, considerations of time have compelled me to restrict to a minimum my references to foreign work.

Some types of fossil must have attracted attention in this country from very early times. The crinoid ossicles of the Carboniferous Limestone, for instance, had been called 'St. Cuthbert's Beads', presumably because of some tradition that they had been used as such by that devout ascetic in his devotions in his Farne Islands retreat. As early as 1586 William Camden, in his *Britannia*, told of the snake-stones (ammonites) of Keynsham and Whitby, which, according to legend, had been transformed by pious virgins, Keina and St. Hilda, from living serpents, that they might no longer sting or tempt mankind. The disbelieving Camden, however, thought it more likely that they had been fashioned in their present state by Nature, for what he calls 'diversion after a toilsome application to serious business'. In the care-free days before the Weights and Measures Act and interfering inspectors, specimens of the sea-urchin *Clypeus*, termed 'pound-stones', had long been used as pound weights by dairy-women in Cotswold village markets.

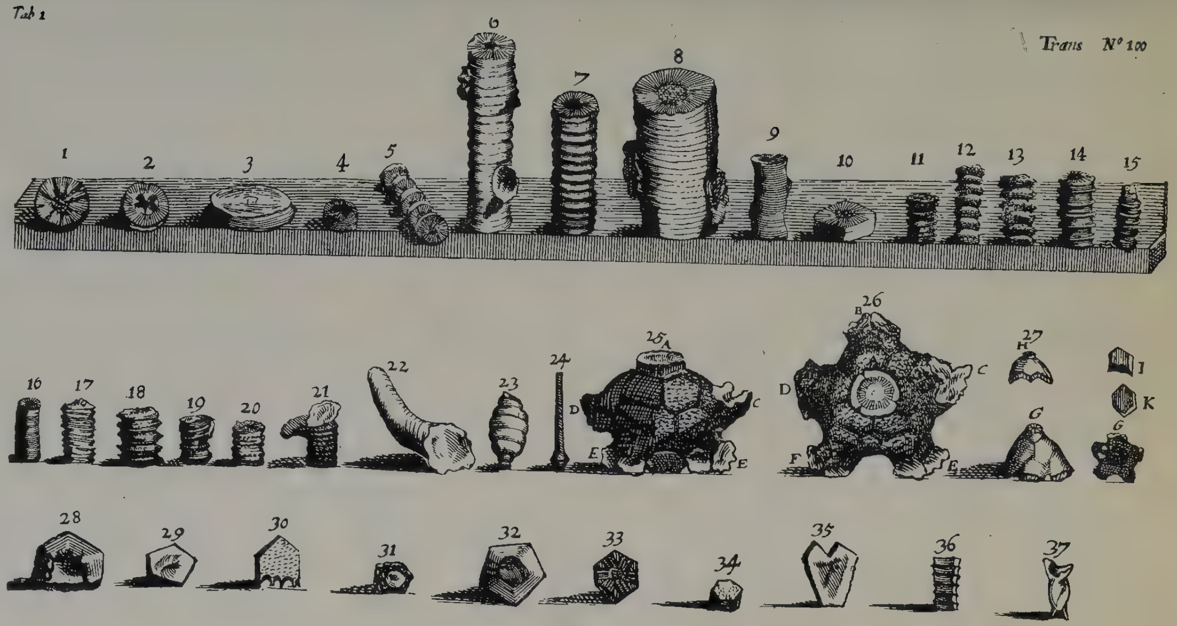
In this country the serious study of fossils dates from the period of awakening interest in science which coincided with the Civil War and the Restoration. The earliest British writer to refer to fossils repeatedly was J. Childrey, who, in his *Britannia Baconica* (1661), told of localities where could be found, not only snake-stones and star-stones, but also cockles, periwinkles, oysters, scallops and mussels, preserved in solid stone. At Huntly Nab, in Yorkshire, he recorded, were found stones of 'diverse bignesses' so rounded that you would think 'they had been turned for shot for great Ordnance'. They could be broken by heating them to redness in the fire and then quenching them in cold water, and in them were found stony serpents, like those of Aderley and Keynsham, but mostly headless.

In passing I can mention only two curious tracts of this same period, T. Lawrence's *Mercurius Centralis* (1664) and W. Somner's *Chartham News* (1669), the latter describing some 'strange and monstrous bones' dug up at Chartham, near Canterbury. These remains, still preserved in the British Museum (Natural History), London, are now known to have belonged to Pleistocene *Rhinoceros*.

The real founders of British palaeontology, however, were those three eminent naturalists of this period, Robert Hooke, Martin Lister and Richard Plot, all early Fellows of the Royal Society, which latter had received its Charter in 1660. The interest in fossils shown by Hooke, the Society's Curator of Experiments, was incidental to other studies, but in his *Micrographia* (1665), a work devoted primarily to the description of objects seen under the microscope, he dealt with the structure of petrified wood, and also described in considerable detail the structures of the snake-stones or serpentine-stones of Keynsham, giving a clear description of their sutures and chambers. He was unable to avoid the conclusion that they were the remains of actual shell-fish. Most of his observations on fossils were published posthumously, in 1705. His drawings—notably those of ammonites—were of a high standard. As is well known, Hooke foretold that one day it might be possible to 'erect a chronology' from the study of fossils.

Lister, a physician practising at York, combined the study of fossil invertebrates with that of modern shells. He was responsible for the earliest published figures and descriptions of British fossil invertebrates, which appeared in the *Philosophical Transactions of the Royal Society* in 1674 and 1675, and were of Carboniferous crinoid remains (including the 'St. Cuthbert's Beads' already mentioned) and of Liassic star-stones or *Pentacrinus* stems. His chief works, which contained illustrations of a number of fossil shells, appeared in 1675 and between 1685 and 1692. In spite of his interest in modern shells, he strongly refuted the views of those who, like Steno and Hooke, regarded fossils as the remains of living creatures. In his view they were merely 'figured' stones, that is, shaped stones, which imitated organic bodies.

Plot, the third of the trio, had been appointed the first Keeper of the Ashmolean Museum at Oxford by its founder. His *Natural History of Oxford-shire*, which appeared in 1676, is notable for its excellent illustrations of the Jurassic fossils of the county. His *Stafford-shire* was published



EXPLANATION OF PLATE

Illustrations of 'Certain Stones figured like Plants, and by some Observing Men esteemed to be Plants petrified', published by M. Lister (1674, *Phil. Trans.*, **8**, No. 100). (Reduced × 0.65.) The fossils represented are crinoid remains from the Carboniferous of Yorkshire and the Lias of Northamptonshire

ten years later, and introduced its readers to Silurian and Carboniferous invertebrates in a similar way. His views on the nature of fossils coincided with those of Lister.

Plot was succeeded at the Ashmolean by a Welshman, Edward Lhwyd, who made a special study of British fossils and published his *Lithophylacii Britannici Ichnographica*, the first attempt to compile a catalogue of them, in 1699. He listed 1766 items divided into twelve Classes (the first, however, consisting of mineral crystals), and he also coined a large number of what would now be termed generic names. He illustrated about 250 of the forms catalogued, but his figures are much cruder than those of Plot.

After this early burst of enthusiasm, the study of fossils proceeded at a leisurely pace in this country during the eighteenth century. Occasional papers appeared in the *Philosophical Transactions of the Royal Society*, among them W. Stukeley's account (1719) of a skeleton from the Lincolnshire Lias now known to have belonged to *Plesiosaurus*. Several general works of interest to palaeontologists also appeared during this period. Among them were topographical works following the style which Plot had set, namely C. Leigh's *Natural History of Lancashire* (1700–1), with a good plate of fossil plants, J. Morton's *Natural History of Northampton-shire* (1712), with several plates of Jurassic invertebrates, and S. Dale's *History and Antiquities of Harwich* (1730), with its figures of Crag shells and the well-known illustration of the low cliff at the mouth of the Stour with fossiliferous Crag overlying London Clay.[1]

Although I have been using the word 'fossil' in its modern sense, it must be remembered that until long after the period of which I am speaking it was used to denote any distinct body, mineral or otherwise, found below the earth's surface. With the recognition (which soon became fairly general) that the 'figured stones' or 'formed stones' of the earlier authors were remains of real organisms, they now became very frequently referred to by Morton's term 'extraneous fossils', since, unlike mineral crystals, they were thought to be foreign to the rocks in which they occurred and to have been introduced by some process not understood. This term persisted until early in the nineteenth century.

An important work of the earlier part of the eighteenth century was John Woodward's *Attempt towards a Natural History of the Fossils of England* (1728–9). Woodward, who was Professor of Physick at Gresham College, devoted all his surplus energy to building up a very large collection of minerals and fossils, of which this work is a catalogue. It contains no figures, but, where possible, there are references to illustrations in the older works. Woodward gave much information about the localities of many of his specimens. He was quite sure that the 'extraneous fossils' catalogued were the actual remains of marine organisms. He bequeathed his collection to the University of Cambridge where it is still kept in the room of the Professor of Geology, the title of whose Chair commemorates his name.

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[1] This illustration was reproduced in these *Proceedings*, 1953, **64**, pl. 4.

In papers published by the Royal Society from 1747 to 1765 there was much speculation about the nature of belemnites, variously suggested to have been of mineral origin, to have been secreted by polyps, and to have been the shells of a chambered marine animal analogous to the *Nautilus*. We may also note the first description, by C. Littleton, of what was described as a 'nondescript petrified insect', from Dudley—the well-known Trilobite *Calymene* for which a Geologists' Association party searched with no great success not long ago. Also there were papers on vertebrate remains from the Lias and Stonesfield Slate and on plants from the Coal Measures, together with one by James Parsons on fossil fruits and other remains from the London Clay of Sheppey.

The year 1758 was an important milestone in the history of biology, for then appeared the tenth edition of the *Systema Naturae* of the Swedish naturalist Linné, in which was perfected a system by which every species was given a name consisting of two Latin words, the first being the name of the genus in which it was classified, and the second, usually an adjective, an epithet appropriate to the particular species. The idea of genera and species was, of course, very old, and haphazard systems of Latin nomenclature, some involving the use of generic names, had been employed by previous writers. Linné, however, enjoyed great prestige. Soon the advantages of his binominal system began to be appreciated generally, and gradually the clumsy old names were abandoned in favour of new ones based upon it. Another practice in which authors began to follow Linné was that of giving a formal diagnosis when establishing a new genus or species. The Linnean system was introduced into British palaeontology by D. C. Solander, an official of the British Museum, who was a Swede and a pupil of Linné. His work, *Fossilia Hantoniensia* (1766), describing fossils from Barton collected by Gustaf Brander, is well known to students of Eocene fossils. Brander himself, a Trustee of the British Museum, was a successful business-man much interested in natural history.

After the early 1770s there was a distinct waning of interest in fossils on the part of the acknowledged leaders of science in the country. Until 1773 papers on the subject had appeared at fairly frequent intervals in the *Philosophical Transactions of the Royal Society*, but between that year and 1813 the Society published none at all on British fossils. Those who kept the lamp burning were, indeed, mainly men of a different type—enthusiastic amateurs. Among them I may mention J. Walcott, whose *Descriptions and Figures of Petrifactions found near Bath* appeared in 1779; W. Martin, an impecunious drawing master whose earlier years had been spent on the stage, and who in 1793 produced his *Figures and Descriptions of Petrifactions collected in Derbyshire*, a work of fundamental importance for students of Carboniferous invertebrates; and the Rev. D. Ure, whose *History of Rutherglen* with its descriptions of Scottish Carboniferous fossils appeared in 1793.

John Parkinson, to whom we now come, was a medical man with advanced political views but a grandmotherly mentality, who had produced a number of popular pseudo-medical works with such titles as 'Medical Admonitions to Families', 'Dangerous Sports: A Tale addressed to Children', and 'Observations on the Excessive Indulgence of Children'.[1] He formed a considerable collection of fossils, and in 1804 began the publication of his *Organic Remains of a Former World*, two further volumes of which appeared in 1808 and 1811. The work was an attempt at a comprehensive but popular account of fossil plants and animals, and, to increase its popular appeal, it was written in the form of a series of letters describing a journey in the company of a fictitious companion, Wilton. Although seldom consulted nowadays, it served to keep an interest in fossils alive during a somewhat barren period. In 1822 Parkinson produced the first elementary text-book on fossils to be published in this country, calling their study 'oryctology', a name which appears to have originated in France and was never generally adopted. The word 'palaeontology' was coined[2] in 1834 by Fischer de Waldheim in Poland, and soon found general favour.

Of greater importance to future workers was James Sowerby, a teacher of drawing, whose first interest in natural history had been the illustration of plants. Having completed his *English Botany*, he turned to minerals next, producing his *English Mineralogy*, and then began to illustrate fossils. In his *Mineral Conchology of Great Britain*, which commenced to be published in 1812, Sowerby embarked upon the naming, illustration and description of the fossil shells of this country, dealing with them, not in systematic order, but as they were brought to his notice by correspondents throughout the country. In an introductory remark he stated that the large numbers of fossil shells found in the excavations for the Archway at Highgate had led to his final decision to start the publication of this work. From James Sowerby there descended a long line of artist-naturalists. A son, J. de C. Sowerby, continued the publication of the *Mineral Conchology* after his father's death in 1822. The work continued to appear until 1845, by which time the activities of various publishing bodies left little scope for a private enterprise of this nature. The importance of the *Mineral Conchology* is shown by the large number of fossil molluscan and brachiopod names which have the name of one of the Sowerbys appended to them, as author.

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[1] An interesting biography of J. Parkinson, by A. D. Morris, appeared in *The Lancet*, 9 April 1955, 761–3.

[2] More strictly in adjectival form, in the title of his work *Bibliographia Palaeonthologica*.

The first two decades of the nineteenth century brought an entirely new outlook on fossils and their study. At the beginning of the century they were regarded as curiosities of interest mainly to collectors, and it was not suspected that any practical use would be found for their study. The advent of William Smith and his demonstration that everywhere the stratified formations were arranged in a definite order and could be identified by the fossils in them is a well-known chapter in the history of geology. Smith published his great geological map in 1815, and in the following year began to publish an uncompleted work, *Strata identified by Organized Fossils*, in which the characteristic fossils of each formation were illustrated. Not every worker was quick to accept his views. In 1815 the distinguished Scottish naturalist, John Fleming, in a paper on Carboniferous *Orthoceras*, remarked that the presence of particular characteristic fossils in each formation could 'not be considered as the expression of a general law in the distribution of organic remains', and in 1819, G. B. Greenough, who had been the first President of the Geological Society of London, argued at length that Smith had much overrated the utility of fossils for identifying stratified rocks. Already, however, an ever growing body of workers was investigating the succession of the strata in all parts of the country and finding that Smith's conclusions were to be relied upon. Thenceforward no work on stratigraphy was considered complete unless accompanied by the description or citation of fossils. The study of fossils had become an integral part of geology.

From 1820 onwards the pioneers of British stratigraphy built rapidly on the foundations laid by Smith. Gideon Mantell described the Cretaceous rocks of south-eastern England; Young and Bird, followed by John Phillips, dealt with the formations of Yorkshire; Samuel Woodward described the Chalk and Crag of Norfolk; W. H. Fitton dealt with the Mesozoic rocks of southern England, and the Lower Palaeozoic rocks of the Welsh Borderland were described by R. I. Murchison in his *Silurian System*. The works of all these authors included descriptions and illustrations of the characteristic fossils of the various formations. In some cases the fossil descriptions and illustrations were entrusted to J. de C. Sowerby and others. Samuel Woodward, who was his own artist, was the first representative with whom we meet of a family which produced three generations of distinguished palaeontologists.

The period of which we are writing was also one of rapid advance in the study of the morphology of fossils in comparison with the living animals and plants. Sir Everard Home, an eminent surgeon, revived the interest of anatomists in fossil vertebrates by several papers in the *Philosophical Transactions of the Royal Society* from 1814 to 1820, describing remains of Liassic *Ichthyosaurus* (which he called *Proteosaurus*). Thereafter, vertebrate palaeontology made rapid strides, thanks to the studies of H. T.

De la Beche, W. D. Conybeare, W. Buckland, G. Mantell, and, ultimately, Richard Owen, as well as to the energetic collecting of Mantell himself, the famous Mary Anning, of Lyme, and others. This was the time when the cliffs and foreshore between Lyme and Charmouth disgorged magnificent saurian specimens year after year. At present the collector may search there in vain for a single vertebra.[1]

At this point we must not forget the ebullient Thomas Hawkins, who early in life was caught up in the wave of enthusiasm for fossil collecting, and who wrote later: 'I was twenty. . . . At that early time my collection of fossils was confessedly splendid, and all the world, of course, on the *qui vive* about it. Spurzheim once told me that I possessed the largest acquisitive organ he ever felt—in 1832 [he was then twenty-one] my collection was Titanic.' "You carry away whole quarries", observed the eminent De la Beche.' Hawkins amassed a fine collection of saurian remains, and in 1834 and 1840, although even then only thirty, published two huge folio monographs on the great sea-dragons, as he called them, more remarkable, perhaps, for their florid style than for the scientific value of their contents.

These were the days when books and illustrations intended to popularise the new fossil-lore began to appear. Mantell led the way with his *Wonders of Geology* (1838), with its gruesome frontispiece of an *Iguanodon* struggling with two other reptiles on some tropical shore in the gloom of sunset, watched by a *Pterodactyl*, chirping and flapping its wings in anticipation of the feast to come. Hawkins countered this with a still more blood-curdling picture by the same artist (John Martin) of a death-struggle between ichthyosaurs and plesiosaurs in the light of the full moon, with the same chirping *Pterodactyl*, translated back some fifty million years, as audience. De la Beche also produced a picture of a squabbling saurian population of the Jurassic seas.

The first British monographs on fossil plants also appeared at this period. E. T. Artis's *Antediluvian Phytology*, illustrating Coal Measure plants, was published in 1825, and Lindley & Hutton's *Fossil Flora of Great Britain*, which was more or less the counterpart of the *Mineral Conchology* by the Sowerbys, from 1831–7. J. S. Bowerbank, in 1840, produced his *History of the Fossil Fruits and Seeds of the London Clay*. Two notable works on an invertebrate group, both combining a study of the living forms with that of the fossils, and both published at Bristol, were J. S. Miller's *Natural History of the Crinoidea* (1821) and T. & T. Austin's *Recent and Fossil Crinoidea* (1843–7).

Not every worker, however, could arrange for the private publication of monographs, and there was a limit to the number of short papers on fossils which the Geological Society of London, and the few other scientific journals in existence at this period, could publish. In London, a band of enthusiasts, among them J. S. Bowerbank, S. V. Wood, F. E. Edwards and N. T. Wetherell, had formed the London Clay Club in about 1836, and in 1847, with the technical assistance of two of the Sowerbys, they decided to form a society for the illustration and description of British fossils. In this way there originated the Palaeontographical Society. Its first volume dealt with the Crag mollusca and the second with Eocene mollusca and reptiles. Before long the Society's monographs covered fossils of many groups and systems.

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[1] The Church Cliffs at Lyme were in process of being walled up with concrete when a Geologists' Association party visited this locality in August 1955.

The 1840s may be considered to mark the beginning of the period of intensive systematic work on British fossils which has continued (latterly, perhaps, with some slight abatement) to the present day. The terminology and methods of description soon became more or less standardised, and, for purposes of illustration, the art of lithography was now available, to supplement and ultimately to supersede that of copper engraving, of which art the Sowerby family long continued to provide leading exponents. Lithography remained the usual method of reproducing plates of illustrations until about 1900, when it was replaced rather rapidly by photographic methods. During the present century, moreover, the photographer has come largely to supersede the artist in the preparation of the original illustrations. Since not every fossil is a good subject for the photographer, the change has not been altogether for the good.

The Geological Survey, established in 1835, began to issue a serial publication in 1849 entitled *Figures and Descriptions illustrative of British Organic Remains*. This continued until 1872, to be succeeded by occasional palaeontological monographs, the most outstanding of which is R. Kidston's work on Coal Measure Plants (1923–4). Publication of so-called catalogues of fossils by the British Museum began in 1877. Latterly the longer ones have been given the more appropriate title of 'monograph' and have included the very fine works on Old Red Sandstone Cephalaspids by Stensiö and on London Clay plants by Reid & Chandler.

To attempt any adequate review of the history of British palaeontology during the past eleven decades would require very much more space than is available here. It is a science to which amateurs and professionals alike have always contributed—at first, perhaps, to an almost equal extent. Nowadays, men of independent means (as were Searles Wood, T. Davidson, and, indeed, Charles Darwin), able to devote much of their time to scientific work, are very few, but amateurs are still among our leading palaeontologists. Workers whose names already figure in the literature of the 1840s include Richard Owen, P. de M. G. Egerton, James Buckman, E. Forbes, Searles Wood, J. Lycett, J. Morris, F. E. Edwards, F. McCoy (who soon migrated to Australia), and the unfortunate H. E. Strickland and J. W. Salter. The 1850s saw the arrival, as active workers, of Charles

Darwin and T. Huxley, H. Falconer, Rupert Jones, D. Sharpe, J. Leckenby, T. Wright, of Cheltenham, who monographed the fossil echinoderms and the Lias ammonites, and Davidson, the first and last man to have a name for every British brachiopod. With the 1860s came Ray Lankester, remembered personally by some of us, Boyd Dawkins, Charles Moore, Henry Woodward, Martin Duncan, R. Tate and R. Etheridge. And so, decade by decade, we could continue the list of new workers who began to make their contributions to our knowledge of British fossils, until we reach the present day.

It remains for me to say something about the changes in the theoretical approach to the study of fossils which have taken place during the past hundred years. While the earlier nineteenth century palaeontologists merely sought to discover, classify and describe, their successors have tried to disclose more and more of the natural laws that have governed the succession of life through the ages. Since, however, the interpretation of the facts is usually by no means unambiguous, one result has been that, instead of being purely objective, the approach of some workers has become subjective to a varying extent.

The theory of descent by gradual modification had been voiced in France by Lamarck early in the century, but at first it was not considered to be the thing for respectable British workers to have anything to do with it. De la Beche and Buckland, for instance, made this quite clear in 1821 when they described *Plesiosaurus*, and for a long time palaeontologists in this country progressed with their work without indulging unduly in speculation. The appearance of Darwin's *Origin of Species* in 1859, and the publicity and controversies which ensued, changed all this. Speculations on descent began to form an integral part of palaeontological papers, new genera and species began (in some cases) to be founded largely on preconceived theories, and a new vocabulary grew up.

We do not owe these developments to Darwin and his associates so much as to those who had alternative theories to propound or claimed to have found short cuts to the reconstruction of evolutionary history. Haeckel, in Germany, who invented those now overworked words 'ontogeny' and 'phylogeny', elaborated the Law of Recapitulation originally suggested by Müller, and Hyatt, in America, in applying this so-called 'law' to the hard parts of which invertebrate fossils consist, let loose a spate of impressive terms which workers found were just what was wanted to add the necessary air of learning and authority to their speculations. Even now new terms arrive with every consignment of literature crossing the Atlantic, and serve to make certain types of palaeontological publications gloriously unintelligible. While the Law of Recapitulation was regarded almost as an article of the palaeontologist's creed fifty years ago, it has now many doubters, or has even tended to be superseded by a theory of prognostication (that of 'proterogenesis') which is almost its converse. Lately, however, the whole topic has been much less in the limelight.

There were some who clearly saw that discussion of the laws of evolution should, by a fundamental law of science, be preceded by a careful study of the facts, and that we can hope to discover the details of modification by descent only by the painstaking collection of large numbers of fossil specimens, bed by bed. The researches of Rowe on *Micraster* and Carruthers on *Zaphrentis* are examples of the successful application of methods approaching this ideal, but a more usual experience is that the fossil record in any particular area and, indeed, as a whole, is too discontinuous for it to be possible to trace the course of evolution in any detail.

Another type of problem demanding the accurate collection and identification of fossils has, however, occupied many workers—that of the zoning or subdivision of our stratified formations by studying the ranges of selected species or genera found in them. The idea of fossil zones originated in 1856 with the German palaeontologist A. Oppel, who had compared our Jurassic succession with that of his own country, and almost immediately his zonal scheme was adopted here by Thomas Wright and other authorities on our Jurassic rocks. The zoning of other systems, in which trilobites, graptolites, brachiopods, corals and other groups have all played a part, was accomplished more gradually. That of the Coal Measures by non-marine lamellibranchs, begun by Wheelton Hind, has been perfected by the late Sir Arthur Trueman and his pupils within comparatively recent memory. The views of S. S. Buckman, which were that the geographical distribution of ammonites was so wide and their time-ranges so short that there could be virtually no limit to the precision with which Mesozoic rocks throughout the world could be subdivided and correlated with their aid, gave rise to much controversy forty years ago. It is now generally admitted that, although stratigraphy could not have advanced to anything approaching its present stage without the help of fossils, the possibilities of ever increasing precision in the use of fossils for dating rocks are, as common sense would suggest, not unbounded.

Among the new developments in palaeontological practice during the thirty-five years, or so, of my own close connection with the science, two call for special mention. The first is the incoming of statistical and graphical methods; and the second is the attempt to follow the trend in neozoology, whereby the study of ecology, physiology and genetics has tended to relegate to a subordinate position work of a purely morphological and taxonomic character. Speaking of statistical methods, an American palaeontologist has remarked that 'in any branch [of science] the qualitative outlook has been the mark of its youthful stages, and the assumption of a quantitative outlook has marked the beginning of maturity', from which we infer that palaeontology in its mature stage will be a science of statistical studies. What development will mark its old age one can only guess. Statistics, which place emphasis upon the study of a whole population rather than upon selected individuals, are a useful addition to purely qualitative work in some circumstances, since they help to give a more thorough picture upon which conclusions as to specific homogeneity and evolutionary progress can be based. They are never likely to be of more than limited utility in palaeontology for three reasons. First, it is only in relatively rare cases that fossil species are found in sufficient abundance in any particular bed, and in a suitable state of preservation, for statistical treatment. Secondly, we can seldom be certain that specimens from the same bed belonged to an even approximately contemporaneous population. Thirdly, statistical methods can be applied only to those characters of an organism capable of numerical measurement or assessment. A complicated shape or an elaborate system of ornament may be of much more fundamental importance than length and height.

The desire to consider fossils primarily from the viewpoint that they were once living creatures which moved, fed and bred, and lived in harmony with their environment is a very laudable one. Unfortunately, however, there is all the difference in the world between the type of observation which the neontologist can make on living creatures in the nature reserve or marine station and the still picture, which the palaeontologist must restore to life, of skeletal remains which have often been carried far from their habitat. If there is clear evidence that fossil remains are still in their original habitat, or if significant structures are preserved, by all means let us pay the utmost attention to any evidence as to the ecology and life-habits of the creatures which they represent. Nevertheless, conclusions based on ambiguous data supplemented by imagination cannot be of the same order of reliability as those which the student of living animals and plants can base on direct observation.

I do not accept the view that the morphological study of fossils has marked the immature phase of a science destined to evolve on some higher intellectual plane. By the very nature of his material the palaeontologist cannot hope to keep up with all the latest fashions of the neontologist. He must always remain primarily a morphologist.

If it is thought that, in view of the long history of research which I have tried rapidly to review, British fossils no longer offer any scope for morphological studies, I must hasten to remove this impression. Whatever phylum or geological system we consider, we find that the scope for future work is still almost unbounded. As an instance we may take the lamellibranchia and gastropoda. These were among the very earliest fossils to have been described, but even at the present day only the Devonian, Carboniferous, Corallian and Cretaceous lamellibranchs and the Inferior Oolite and Pliocene gastropods are covered by adequate monographs, and many species, even from the Eocene of southern England, are still undescribed. Similar statements could be made about most other invertebrate groups. In particular, our microfaunas will offer a rich field for research for many years to come.

Members of the Geologists' Association have contributed much to the progress of British palaeontology, not only by the large collections which many have built up and bequeathed to posterity, but also, in many cases, by their own scientific work. In this connection I need only remind you of the late Mr. Arthur Wrigley, who, although his spare time was very limited, had to his credit many first-class papers on material largely of his own collecting. The exhibits at our Reunions show that there are still many enthusiastic students of fossils among our members, including the younger ones. We may rest assured that there is still a great future for palaeontology in this country, in which our members, amateur as well as professional, will play a big part.

The Stratigraphy and Structure of the Chalk of the Dean Hill Anticline, Wiltshire

by E. WILLIAMS-MITCHELL

Received 9 March 1955

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ABSTRACT: The paper consists of a report on the mapping of the Dean Hill anticline as carried out for the Anglo-American Oil Co. Ltd. in 1946. The work involved the mapping of Upper Chalk zones on the lines laid down by Brydone (1912). Both the stratigraphy and the structure are simple. Although an equivalent of the *Hagenowia* Beds of Gaster (1924) was noted, it was found necessary to adopt Brydone's original zonal scheme, using the *planoconvexus* bed as the top of the subzone of *Offaster pilula*.

1. INTRODUCTION AND ACKNOWLEDGMENTS

THE DEAN HILL ANTICLINE is situated on the borders of Hampshire and Wiltshire some five miles south-east of Salisbury athwart the main road to Southampton (see map facing p. 222). It is bounded on the south and east by the Eocene Beds of the Hampshire Basin and on the north by a synclinal tongue of Eocene Beds running westwards from Grimstead through Clarendon to Alderbury. This tongue partly isolates the anticline from the main Chalk tableland of Salisbury Plain to the north. The geology has been described briefly by Reid (1903, pp. 57–60) and more fully by White (1912, pp. 34–40, 60, 62). The eastern extremity of the area was included in the zonal map of the Chalk of Hampshire published by Brydone (1912).

The topographic features of the area are those typical of Chalk downland. South of the wooded Eocene country to the north the land falls to the east–west Dean Valley, occupied by the northern flank of the anticline. On the south side of this valley the Dean Hill ridge rises steeply to a maximum elevation of 512 ft. O.D., near its eastern end, with a general crest between 400 ft. and 500 ft. Southwards the land falls gently, and with rounded outlines, to the wooded Eocene country of the New Forest.

The work was planned as the preliminary part of a survey of the geological structure of Salisbury Plain, with a view to exploration for oil by the Anglo-American Oil Co. Ltd., but operations were abandoned before the major part of the work was undertaken. Grateful acknowledgment is made to the Directors of the Anglo-American Oil Company for their permission to publish the results of the work in the Dean Hill area. The author's palaeontological determinations, on which the map is based, were confirmed by Mr. R. V. Melville of H.M. Geological Survey. Thanks are due to him, and to the Director of the Geological Survey, for permission to incorporate the results of this work in the present paper. The fossils collected in the course of the investigation have been presented to the Geological Survey and Museum by the Directors of the Anglo-American Oil Company. Thanks are also due to Mr. C. W. Wright for assistance in determining the starfish ossicles recorded.

2. METHODS

The work consisted of zonal mapping of the Upper Chalk on a six-inch scale in accordance with methods laid down by Brydone (1912), i.e. by the macropalaeontological determination of horizons at as many points as possible and by linking these points by lines drawn according to the ordinary principles of field-mapping. The available exposures were limited to a few old chalkpits, most of which had to be dug out before collecting was possible. Many of the data were obtained from auger-holes and hand-dug pits. The thickness of one stratigraphical unit (the sub-zone of *Offaster pilula*) was found from a series of nineteen such pits, dug within a distance of 200 ft., which exactly fixed the positions of the top and bottom of the sub-zone. Every exposure was levelled with a hand-level, used in conjunction with a graduated staff, and using the nearest bench-mark as a datum. In the later stages of the work a Paulin altimeter was used to check the earlier observations.

Foraminifera, though not specially studied, proved helpful in indicating horizons at localities where macrofossils were not found (see Williams-Mitchell, 1948).

3. STRATIGRAPHY AND FAUNAL SUCCESSION

The beds here described are in the upper part of the Upper Chalk. Their development in the area is shown below:

ZONE		ft.
Belemnitella mucronata		50 seen
Gonioteuthis quadrata		195
Offaster pilula	Sub-zone of *O. pilula*	45
	Sub-zone of *Echinocorys scutata* var. *depressula*	60
Marsupites testudinarius		28
Uintacrinus westfalicus		26
Micraster coranguinum		50 seen
	Total	454

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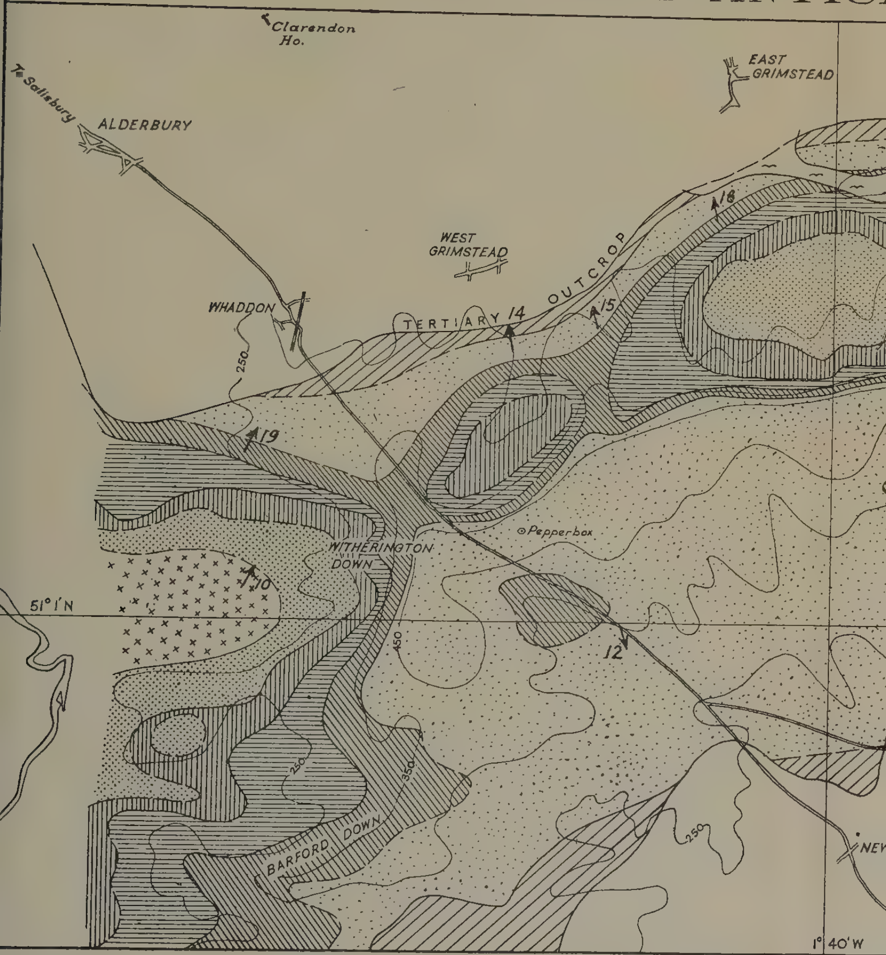
DEAN HILL ANTIC



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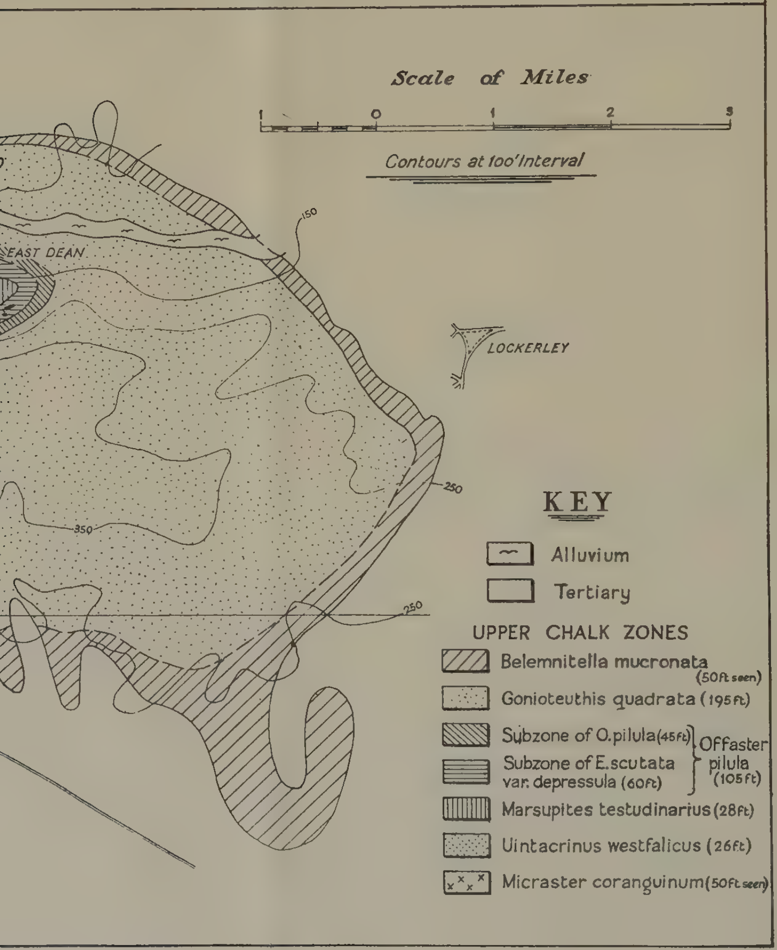
Scale of Miles
1
0
1
2
3
Contours at 100' Interval
150
EAST DEAN
LOCKERLEY
250
350
250
KEY
Alluvium
Tertiary
UPPER CHALK ZONES
Belemnitella mucronata (50ft seen)
Gonioteuthis quadrata (195ft)
Subzone of O. pilula (45ft)
Subzone of E. scutata var. depressula (60ft)
Offaster pilula (105ft)
Marsupites testudinarius (28ft)
Uintacrinus westfalicus (26ft)
Micraster coranguinum (50ft seen)

[*To face p.* 222

Zone of Micraster coranguinum (50 ft. seen): In the Salisbury district the full thickness of this zone is estimated by Jukes-Browne (1904, p. 71) to be 240 ft., but only the top 50 ft. were encountered in the present survey. The beds, which are relatively unfossiliferous when compared with the top part of this zone in Kent, occur at the western extremity of the area studied and the zone spreads farther westwards over the broad upland around Bower Chalke. The lithology is that typical of this part of the *coranguinum* Zone in southern England, namely, soft white chalk with many regular courses of flint nodules. Palaeontological evidence of horizon was provided by *Micraster coranguinum* (Leske) of typical form and by marginal ossicles of the starfish *Metopaster uncatus* Spencer.

Zone of Uintacrinus westfalicus (26 ft.): The chalk of the lower part of this zone is hard and fossils occur only sparingly. In the succeeding softer beds *Uintacrinus* occurs, with small *Micraster coranguinum* and marginal ossicles of *Metopaster uncatus*. At the top of the zone there are a few feet of barren chalk below the first occurrence of *Marsupites*, as was observed in Hampshire also by Brydone (1912, p. 16).

Zone of Marsupites testudinarius (28 ft.): The chalk of this zone is soft and white with pale, marly streaks and small, scattered flints. As noted by Brydone, the radiating ornament on the cup-plates of *Marsupites* shows a progressive elaboration from lower to higher horizons. Apart from the zone-fossil, which is abundant, *Echinocorys scutata* Leske var. *elevata* Brydone occurs regularly. Marginal ossicles of *Metopaster uncatus*, columnals of *Bourgueticrinus*, form 5 of Griffith & Brydone, and *Ostrea boucheroni* Coquand, give confirmatory evidence of this zone.

It should be mentioned that detached crinoid brachials were never used to identify either this or the preceding zone in the absence of cup-plates or of the associated fauna.

Zone of Offaster pilula (105 ft.): As in Hampshire, this zone is divided into a sub-zone of *Echinocorys scutata* var. *depressula* below and a sub-zone of (abundant) *Offaster pilula* above.

The depressula Sub-zone (60 ft.): The chalk of this sub-zone is firm and massive, with few flints, and with numerous marl seams in the upper part. Fossils are scarce. *E. scutata* var. *tectiformis* Brydone is found sparingly in the lowest ten feet and var. *depressula* in the middle beds. *Bourgueticrinus* form 6 of Brydone, and small specimens of *Offaster pilula* (Lamarck) also occur. The top ten or fifteen feet of the sub-zone are practically unfossiliferous except for rare *Echinocorys*, usually crushed beyond closer recognition. No satisfactory open sections of the sub-zone were seen.

The pilula Sub-zone (45 ft.), on the other hand, is easily identified by its abundant and characteristic fossils. Most of the critical evidence for the map, and for its structural interpretation, was provided by this sub-zone, supplemented by evidence from the *Uintacrinus* and *Marsupites* zones.

Within ten feet above the base of the sub-zone, *Echinocorys scutata* var. *truncata* Griffith & Brydone occurs abundantly, with *Bourgueticrinus* form 1 of Griffith & Brydone (at its lowest occurrence) and *Offaster pilula* of medium size in the upper part of the band. The middle part of the sub-zone is characterised by *Retispinopora patula* Brydone, *Serpula turbinella* J. de C. Sowerby, *Aptychus leptophyllus* Sharpe, *Bourgueticrinus* forms 1 and 4 of Griffith & Brydone, *Pycinaster magnificus* Spencer, *Stauranderaster pistilliferus* (Forbes), *Echinocorys scutata* var. *cincta* Brydone and *O. pilula* of medium size. The top of the sub-zone is taken at the top of the *planoconvexus* bed of Brydone (1938). In the present area, as in Hampshire, this bed consists of some four feet of chalk between two marl seams and with a band of large flint nodules about the middle of the bed. Among and immediately below these flints there are found numerous specimens of *O. pilula* var. *planatus* and var. *convexus* Brydone.

The limits here adopted for the *pilula* Sub-zone are those originally set by Brydone when defining the subdivision in 1912. In 1924 Gaster advocated the upward enlargement of the sub-zone to include (in the Worthing district) some 60 ft. of chalk which were assigned by Brydone to the next succeeding zone of *Gonioteuthis* [*Actinocamax*] *quadrata*; and he divided the *pilula* Sub-zone into a *depressula* Sub-zone below and a *cincta* Sub-zone above (see, e.g. Gaster, 1951, p. 38). Gaster's argument was based on the occurrence, in the beds in question, of the characteristic fauna of the *pilula* Sub-zone, including such significant forms as *E. scutata* var. *depressula* and var. *cincta*, *O. pilula* and a number of species confined to these beds. Although Brydone (1938) protested against this modification of his original concept, and stated that the fauna of the *pilula* Sub-zone did not range above the *planoconvexus* bed in Hampshire, it is clear that Gaster's claim is well supported by the evidence in Sussex. Theoretically, in a conformable series of uniform beds, where zones can be identified only by reference to palaeontological data, a consistent practice should be followed and beds should not be grouped with one zone when they contain the fauna of another. In practice, however, it was not found possible in the Dean Hill area to map a line corresponding to the highest occurrence of the fauna of the *pilula* Sub-zone, which seems to die out gradually in increasingly unfossiliferous beds rather than to be replaced by a distinct fauna. For the purposes of field-mapping, the *planoconvexus* bed provided an admirable index-bed, easily recognisable both lithologically and palaeontologically; and no comparable horizon was noted in any higher beds of the Chalk below the entry of *Belemnitella mucronata*.

Two chalk pits encountered in the present survey exposed beds near the base of the *quadrata* zone (as here interpreted). At West Harnham Limeworks the upper part of the *pilula* Sub-zone, capped by the *planoconvexus* bed, is succeeded by some twenty feet of barren chalk. In an old pit on the west side of the Salisbury–Southampton road south-west of the Pepperbox is exposed fossiliferous chalk within 50 ft. above the *planoconvexus* bed. The contrast between the two pits may be a matter of slight difference in horizon, for at the pit south-west of the Pepperbox the *planoconvexus* bed is not exposed, though there is probably more than the twenty feet seen at West Harnham. The pit south-west of the Pepperbox yielded *Porosphaera nuciformis* (Hagenow), *Serpula turbinella* J. de C. Sowerby, *S. ampullacea* J. de C. Sow., *Crania egnabergensis* Retzius, *Chlamys cretosa* (Defrance), *Spondylus dutempleanus* d'Orbigny, *Lima* (*Plagiostoma*) *cretacea* Woods, *Bourgueticrinus* aff. form 2 of Griffith & Brydone (of very great size), *Echinocorys scutata cincta* and *Offaster pilula* of medium size. Many of these are long-ranging species, but they were not found in association at any other horizon in the area examined. The abundance of *Chlamys*, *Lima* and *Spondylus* was especially noteworthy.

Of the species listed above, the following are mentioned by Gaster (1924, pp. 103–6) as characteristic of his *Hagenowia* Beds (i.e. the basal 60 ft. of Brydone's *quadrata* zone): *Crania egnabergensis*, *E. scutata cincta* and *Bourgueticrinus* form 2. On the other hand, *Retispinopora lancingensis* Gaster and *Hagenowia rostrata* (Forbes), which are characteristic fossils of these beds in Sussex, are very rare at Dean Hill, while medium-sized *Offaster pilula* is fairly common in the pit south-west of the Pepperbox, but is confined to the base of the *Hagenowia* Beds in Sussex. Thus, while it is possible to recognise an equivalent in Wiltshire of the Sussex *Hagenowia* Beds, the two would seem to differ to some extent in their faunal characteristics, and the Wiltshire equivalent seems to be a less easily traceable unit than does the Sussex original. However, it should be borne in mind that Gaster has examined an enormously larger number of open sections over a far greater area, so that further work in the Salisbury district might indicate some modification of the statements made above.

Zone of Gonioteuthis quadrata (195 ft.): The chalk in the lower part of this zone is harder and contains more frequent flint-bands than does that of the *pilula* and *Marsupites* zones. Fossils are scarce and ill-preserved, so that relative levels within the zone could not be fixed unless the position of the *planoconvexus* bed, or of the base of the *mucronata* Zone, was known. Belemnites are rare, as is general in this zone in this part of the country. The dwarfed form of *Offaster pilula* (var. *nana* Brydone MS.) is characteristic when it occurs. *Saccocoma cretacea* Bather was not detected.

Zone of Belemnitella mucronata (50 ft. seen): The chalk of this zone is soft and white and includes few flint-bands. A pair of marl seams was taken to mark the base of the zone, for between and just above these, *B. mucronata* (*sensu lato*) and *E. scutata* var. *subconicula* Brydone are common. The dwarfed form of *O. pilula* and *Gyropleura inaequirostrata* (S. Woodward) are also characteristic. A small *Serpula*, with seven longitudinal ridges, was also noted.

4. STRUCTURE

Structurally, the Dean Hill anticline is simple. It is an asymmetrical fold, with dips up to 16° N. on the northern flank and about 2° S.–SE. on the southern flank. From the eastern end of the structure the axis runs westwards to a point near West Dean Farm. In this part of the fold the axis lies in the low ground of the Dean Valley and the oldest beds to outcrop are those of the *Uintacrinus* zone. From here the axis turns to the south-west and runs into the escarpment feature and through Witherington Down. South of Alderbury this fold, with south-westerly strike, is replaced *en échelon* by another anticline, with east–west strike, trending towards Bower Chalke, and with beds of the *coranguinum* zone outcropping in the core of the fold.

That part of the Dean Hill anticline with south-westerly strike reveals no beds older than the *Marsupites* zone and is separated from the Bower Chalke anticline, and from the eastern part of the Dean Hill anticline, by saddles of the *pilula* Zone. Thus, all of these three folds appear as windows in a general background of the *quadrata* and *mucronata* zones; and since the greater part of Salisbury Plain is known to be occupied by the beds of the *coranguinum* zone, they are, as it were, perched on the southward-dipping flank of the chalk tableland which forms the northern limb of the Hampshire Basin syncline. The closure of the eastern part of the Dean Hill anticline is 80 ft. at its western end, and of the south-westerly stretch, about 60 ft. Had erosion removed the higher zones of the Upper Chalk, so that these structures were expressed at the surface in beds of the *coranguinum* zone, they would have been much more difficult to detect and map in the current state of knowledge; and it is not impossible that folds of amplitude equal to those here described may await recognition in the main area of Salisbury Plain with the aid of more refined palaeontological methods.

The folding that produced the Dean Hill anticline can be dated to the interval between the lower *mucronata* Zone and the earliest Eocene strata (Reading Beds) deposited in the area. These latter rest on beds of the *mucronata* Zone everywhere on the north and east of the area, except north-west of West Dean, where Reading Beds rest on the *quadrata* Zone. South-west of Whaddon these beds transgress on the *quadrata* and *pilula* zones of the Chalk. The unconformable relationship of the two formations is brought out in a striking way along the southern side of the area, where the base of the Eocene wanders from the *mucronata* Zone to the *quadrata* Zone in an apparently haphazard fashion.

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Slumping in Reading Beds near St. Leonards, Bucks

by C. D. OLLIER and A. J. THOMASSON

Received 26 August 1955

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ABSTRACT: An exposure of disturbed sands and clays, believed to be of Reading Beds age, and situated within two miles of the Chiltern scarp, is described. The disturbances are attributed to slumping soon after deposition, and the relationship to neighbouring outliers of recognised Reading Beds is discussed.

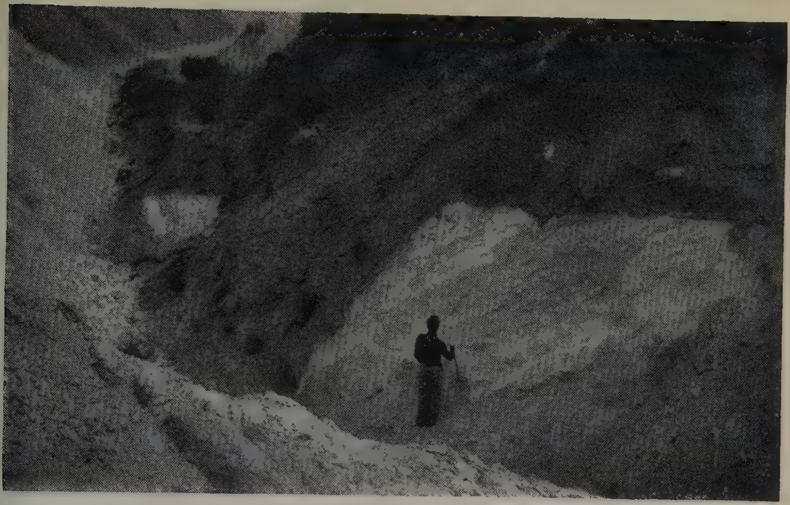
1. INTRODUCTION

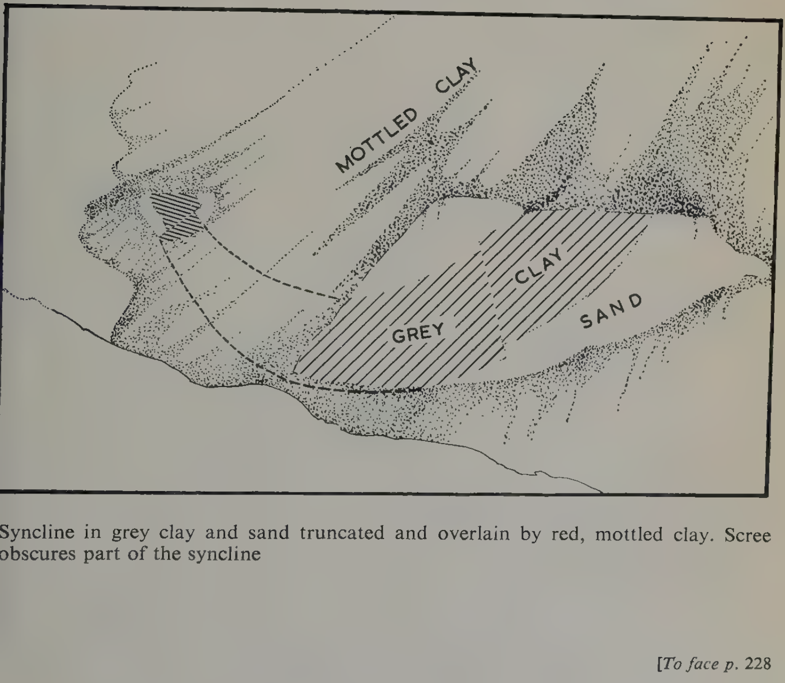
AT CHESLAND, 1400 yards south-east of St. Leonards (National Grid Reference 42/917,060), is an exposure of sands and clays described on H.M. Geological Survey maps as 'Clay with Flints'. The sandpit is situated on a flat-topped ridge between two dry valleys which run from north-west to south-east. The top of the ridge is 620 ft. above Ordnance Datum, and the sandpit reaches a depth of 50 ft. Chalk outcrops in the western valley at a height of about 600 ft., which is 30 ft. higher than the bottom of the pit, where no chalk is exposed. Augering to 3 ft. at a number of points in the eastern valley did not reach chalk, so the exact nature of the chalk surface is not known, but it must have a considerable slope from the flank of the western valley to beneath the pit.

2. DESCRIPTION OF THE DEPOSITS

(a) **Lithology.** The principal deposit exposed is a fine, white, very well-sorted sand. Mechanical analyses showed a median grain-size of below 0.125 mm. ($M\varphi$ 3.2) and an almost symmetrical distribution ($Q1\varphi$ 2.65, $Q3\varphi$ 3.70). The sand consists mainly of quartz, with a very small quantity of flint. The heavy minerals are predominantly opaques of limonitic type, with some zircon, tourmaline, rutile, staurolite and kyanite. Other minerals present in smaller amounts include garnet, muscovite and green hornblende.

Within the sands are bands of clay, sandy clay and bands containing





Syncline in grey clay and sand truncated and overlain by red, mottled clay. Scree obscures part of the syncline

many flints. The bands of pure clay are several feet thick and blue-grey in colour. X-ray diffraction analyses show that 80% or more of the clay is of kaolinitic type, probably rather finely-divided, with minor amounts of talc, montmorillonite and feldspar. The clay from the sandy clay bands has a similar composition. The bands with flints are notable for containing numerous practically unworn, large, white, patinated flints.

Brown sand, clay and sandy clay occur, mostly near the top of the pit, but also as bands and vaguely-defined patches in the white sand. The brown clays are often mottled with red and green-grey colours, and contain bands of shattered flints and flint pebbles.

(b) **Structures.** The white sand is mainly structureless, but in the clay bands structures are well displayed, and the beds are seen to be very contorted. Disturbances are quite disorderly, faults and folds appearing without any general pattern. A synclinal fold (Plate 8) is the largest structural feature, the limbs of which are broken by slight faults. Elsewhere thin sandy clay bands show considerable distortion on a small scale, and two sets of 'joint planes', dipping at about 70°, are filled with clay which has filtered through from higher levels.

Other significant structures are caused by a breaking up of the beds. Lumps of blue-grey clay and sandy clay are found detached in the sand (Fig. 1). No true clay balls are found, but the structures appear very similar to those previously described as evidence for slumping (e.g. Kuenen, 1948; Jones, 1937) and suggest a rapid disturbance of the beds soon after their deposition. The alternating sands and clays provide ideal lithological conditions for this kind of motion. The most conclusive evidence in support of slumping would be to find undisturbed beds above the broken and contorted deposit. At first this might appear to be shown in Plate 8, but is not the case, however, for the apparent plane of unconformity dips steeply, and is probably a fault plane or slump plane.

Tectonic activity could hardly produce such intense folds without any folding of the underlying chalk. The break-up of the beds appears to be too severe and sudden to be attributed to solution of the chalk, or to 'running sands'. There is no direct evidence of glacial activity, and it is not necessary to postulate glacial or perma-frost action to explain these structures.

3. AGE AND SIGNIFICANCE OF THE DEPOSITS

Probably the deposits are of Reading Beds age, but there are no fossils to prove it. However, there can be little doubt that the deposit is of true sedimentary origin and is not a drift. The situation of the sandpit is 50 ft. below the sloping surface of Pliocene marine transgression, as postulated by Wooldridge & Linton (1955), which can be reconstructed from a generalised contour sketch. This, and the general lithology, make it unlikely that the beds are of Pliocene age. Elsewhere in the Chilterns the Pliocene deposits consist mainly of sand and shingle.

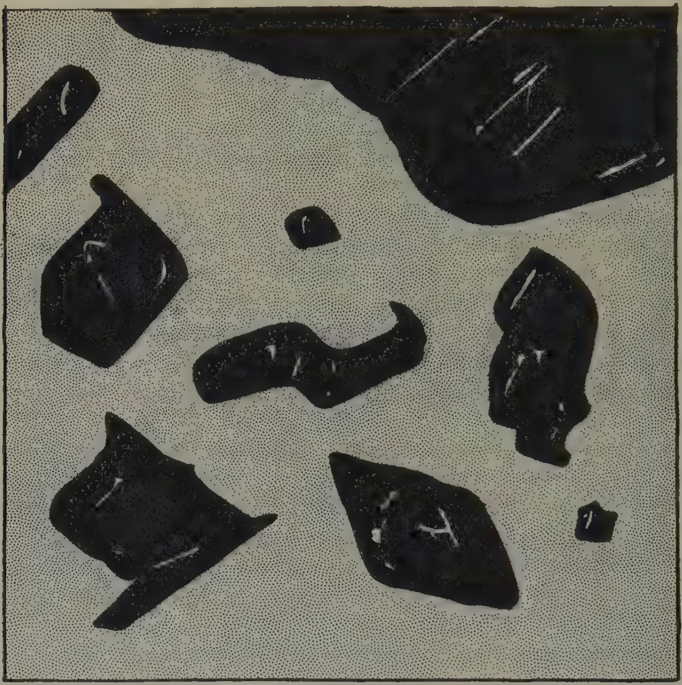


Fig. 1. Detached lumps of clay (black) in sand at Chesland. The area depicted is one yard square

Strong evidence in support of a Reading Beds age is afforded by comparison with known Reading Bed outliers elsewhere in the Chilterns. The general succession of dark clays succeeded by sandy deposits and then mottled clay is frequently found, and numerous instances are given by Wooldridge & Ewing (1935). In fact the Lane End deposits appear to bear a striking similarity to those at Chesland, not only in general succession but also in disturbances present. Steep folds in the lower clays are recorded, and also clay breccias, and in this case the disturbance could not be glacial because the overlying London Clay is unaffected. The mineral assemblage of the Lane End sands is closely comparable with that of the Chesland sands.

At the top of the Chesland sandpit, above the beds described so far, is a drift deposit consisting of a mass of shattered flints of all sizes in a matrix of brown clay. This cuts across the lower beds irregularly and occasionally occupies channels. Its uniformity strongly contrasts with the diversity of the lower beds, which leads us to believe that it is a solifluction deposit and probably a periglacial phenomenon. If this is correct, then the channelling of the surface of the lower beds was the only disturbance they suffered in glacial times.

It may be thought that the angular and little-worn flints in the lower beds at Chesland are evidence against assigning a Reading Beds age to the deposit. Angular flints do, however, occur in the outlier at Lane End, and the likeliest explanation seems to be that Reading Beds in the Chilterns have a basal layer containing unworn flints similar to the Bull Head Bed of other localities, though not so well developed. Slumping, accompanied by lateral movement, may have moved this bed so that now it occupies a position relatively higher in the succession than it did when it was first deposited.

If our conclusions are accepted, then the deposits here described represent another outlier of Reading Beds in the Chilterns 'Clay-with-Flints' drift. Unlike the outliers at lower elevations, these beds are below the general plateau surface, and not a hill rising above it. The lithology is similar to the Reading Beds of Lane End and Cowcroft but perhaps the deposits are even more disturbed. We believe the disturbances can be explained as slump phenomena and suggest that this may also apply to the other outliers.

The writers would like to acknowledge the help and facilities provided by the staff of the Pedology Department, Rothamsted Experimental Station, Harpenden, Hertfordshire.

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The Rock Succession and Geological Structure of the Pyrddin, Sychryd and Upper Cynon Valleys, South Wales

by D. G. JONES and T. R. OWEN

Received 23 July 1955

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ABSTRACT: Detailed successions of the Namurian and lowest Ammanian rocks at the head of the Neath and Cynon Valleys are described. Several fossiliferous horizons have been found, the detailed mapping of which has revealed the existence of a WNW.–ESE. fault-system along the Pyrddin, Sychryd and upper Cynon Valleys. The age of these faults, and their influence upon the development of the drainage of the region, are discussed.

1. INTRODUCTION

THE AREA to be described (Fig. 1) forms a narrow belt extending east-south-eastwards from Abercrave, at the head of the Swansea Valley, to Trecynon, in the upper part of the Cynon Valley, a distance of eleven miles. The region is drained by the Llech (a tributary of the Tawe), the Pyrddin and the Sychryd (both tributaries of the Neath) and the Cynon. The River Neath and its north-eastward continuation, the Mellte, flow south-westwards across the central part of the region.

The belt forms part of the North Crop of the South Wales Coalfield and the regional dip of the Carboniferous rocks is mainly a southerly one. Marked variations occur, however, along the Vale of Neath Disturbance. Apart from the narrow tongue of Avonian strata along this Disturbance, the rocks exposed in the area are of Namurian and Ammanian age.

The geology of the region has been described previously by Strahan (1902) and Robertson (1933). In their description of the Millstone Grit of the North Crop, Evans & Jones (1929) referred to the age of those rocks in this region and described some fossil localities. One of the writers (Owen, 1954) has described the structure of the Neath Disturbance.

Despite these previous accounts of the geology of the area, the writers consider this paper to be necessary, for the following reasons:

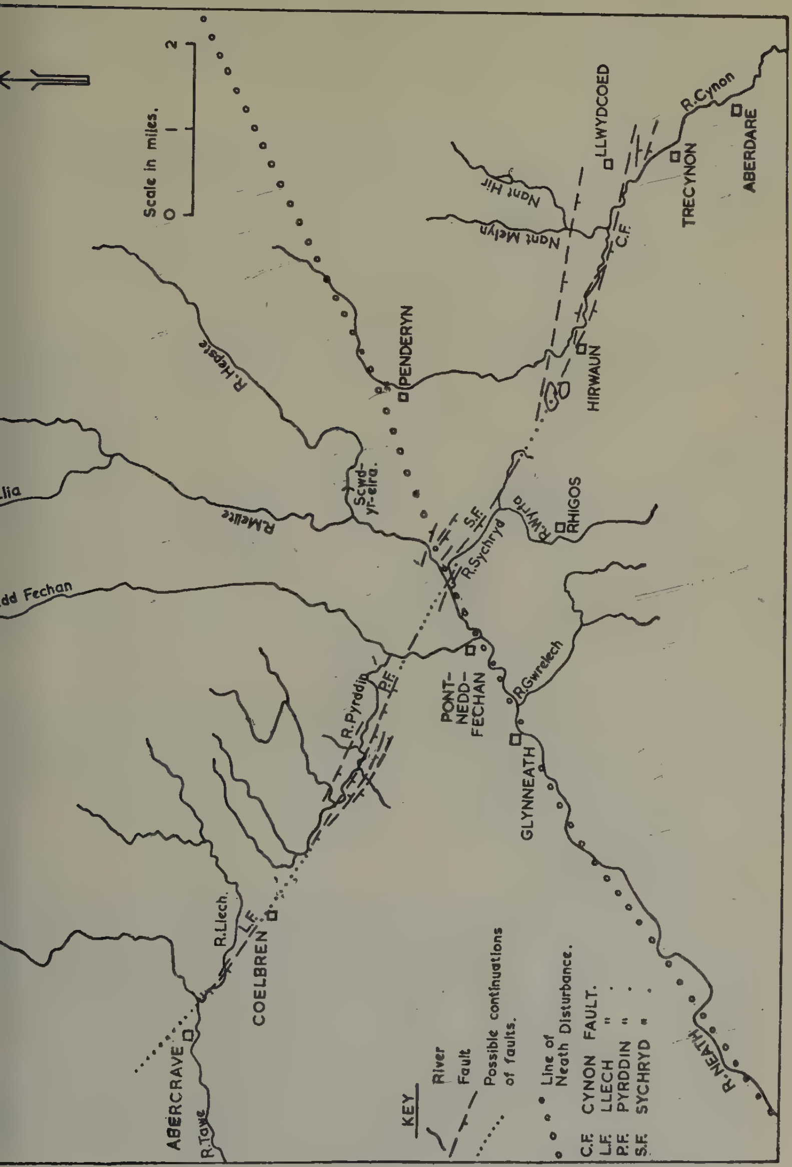

Fig. 1. The Pyrddin–Upper Cynon Fault-System

(i) It has been possible to make a detailed revision of the Namurian succession in the gorges of the Mellte, Sychryd and Pyrddin rivers. Several new faunal and plant horizons have been discovered and the succession compares favourably with that of Carmarthenshire, as described by Ware (1939).

(ii) The *Lenisülcata* and *Communis* zones of the Coal Measures are well exposed in the area, but many of these exposures have not been previously described. Several fossiliferous horizons have been discovered in the *Lenisulcata* Zone, which horizons Professor Leitch and the writers have shown to occur in areas farther west. Recent work by Dr. Huw Jenkins has proved the presence of these marker bands in Pembrokeshire.

(iii) The region has a particular geomorphological importance in that probably it once marked the course of a major tributary of the ancestral Cynon (R. O. Jones, 1939, p. 539; North, 1949, p. 87). Jones considered that this Pyrddin–Sychryd tributary developed along the base of the Pennant Sandstone (1939, p. 539). The discovery of numerous fossiliferous horizons in the Namurian and lower Ammanian strata has enabled the writers to map the region in great detail and this has revealed the existence of an important fault-system along the course of the ancestral tributary. Such a fracture-belt must have determined the position of this earlier river. Moreover, the trend of the fault-system is very different from that of other fractures in this northern portion of the coalfield and compares closely with the directions of the post-Liassic faults in the Vale of Glamorgan.

2. THE NAMURIAN SUCCESSION IN THE AREA

The Namurian strata are approximately 400 ft. in thickness and comprise conglomerates, grits, quartzites, flags and shales. This succession, the upper limit of which is drawn at the *Gastrioceras subcrenatum* Marine Band, is divisible into two groups:

(b) **Shale Group**
(a) **Basal Grit Group**

The lower division consists of siliceous grits, quartzites and conglomerates, with intercalated bands of mainly carbonaceous shale. In the Craig-y-Dinas district, three marine horizons and at least one plant-bed are present, the group being about 150 ft. thick. As shown by Robertson (1933, p. 49), a gradual thinning occurs in an easterly direction over the area.

The upper division comprises grey, blue and black shales or mudstones with thin grits, two of which are particularly persistent. Seven marine horizons, one plant-bed and one mussel-band occur within the group which maintains a thickness of about 240 ft. over the area[1].

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[1] The thickness of the Shale Group in the Neath Valley is eighty feet greater than the estimate given by Robertson (1933, p. 64 and Fig. 8).

(a) **Basal Grit Group.** This division is exposed most completely in the Craig-y-Dinas district, two miles north-east of Glynneath. The most continuous section occurs in the Dinas Quarry, on the southern side of Bwa Maen, and the succession in this quarry has been described by Robertson (1933, p. 58). However, the beds are steeply-dipping and there is some crushing of the softer bands. One line of crush occurs even within the grits (the lowest grit in the quarry) and it is possible that the lowest part of the succession is incomplete. In the River Mellte (upstream from Mellte Bridge), however, the lowest seventy feet of the Basal Grit Group is fully exposed and there is little crushing of the softer beds, two of which have yielded fossils. For these reasons, therefore, the sequence in the Mellte will be described first, the remainder of the succession being taken from the Dinas Quarry. The complete Basal Grit Group sequence is shown in Fig. 2, certain distinctive lithological and fossiliferous horizons being indicated by the letters A to F.

Bed A, best seen on the left bank of the Mellte, 100 yds. above Mellte Bridge, is a coarse black shale with coal streaks. It contains fragments of plants, including *Lyginopteris stangeri* (Stur), which is regarded as characteristic of the *Eumorphoceras* Stage (Ware, 1939, p. 201; Dix, 1933, p. 163). Bed B, black marine shale, contains *Orbiculoidea* sp., fish-scales and fish-spines, the fossils being obtained on the opposite bank of the river, sixty yards above the bridge. These two fossiliferous horizons have not been recorded by earlier workers, and suggest that the lowest beds of the Basal Grit Group in the area are older than was thought by Evans & Jones (1939, p. 168) and Ware (1939, p. 175). It is possible tentatively to correlate bed B with the *Homoceras* band which Ware found in the River Twrch, Carmarthenshire (1939, p. 175). This correlation is supported by the distance of the marine band below the *Reticuloceras* '*inconstans*' horizon and by certain lithological features, such as the presence within the shale of a pyritous gritty layer containing grains of quartz (cf. Ware, 1939, p. 175).

No fossils have been found in the thin bands of coaly shale which occur in the lower half of the Dinas Quarry section, though this may be attributed to crushing. On this account it is difficult to match the lower beds in the quarry with those of the Mellte section. However, the probability is that the thin coal and shale bands occurring 18 ft. and 38½ ft. above the base of the Group in Dinas Quarry (see Robertson, 1933, p. 58) are the plant-bed and *Orbiculoidea* Bed respectively of the Mellte section. In that case the carbonaceous shale (with fine-grained sandstone bands) that occurs 59 ft. above the base of Robertson's section would be equivalent to the irregularly-bedded black shales, with thin sandstone ribs (beds C), that are exposed on the right bank of the Mellte, 200 yds. above the bridge.

A plant-bed does occur, however, about 10–12 ft. above the base of the Group in two nearby localities—at a bridge over the Sychryd, 100 yds.

west of Dinas Quarry, and on the left bank of the river opposite the entrance of the Dinas Silica Levels. This coaly shale contains *Lyginopteris fragilis*, *Sphenophyllum* cf. *tenerrimum* and *Calamites* sp.; *Lyginopteris stangeri* (Stur) has not been found. Therefore the writers hesitate to correlate this Sychryd plant horizon with the *stangeri* bed of the Mellte section, though it occurs at a similar height above the base of the Group.

The carbonaceous shales with fine-grained sandstone bands (possibly beds C) in the Dinas Quarry are overlain by a light-grey or blue-grey quartzite which was the chief bed worked in the quarry. This exceptionally pure quartzite (bed D in Fig. 2) is now being worked extensively in the nearby Dinas Silica Levels.

Twenty-three feet above the quartzite there occurs the lower of two marine horizons, separated from each other by a thin sandstone. The lower band (bed E) is a dark shale with ironstone nodules and containing *Reticuloceras* '*inconstans*'. This marine bed was recorded by Evans & Jones (1929, p. 167) and by Robertson (1933, p. 52). However, they did not record the higher horizon which contains *Reticuloceras reticulatum* (Phillips). The nearness of the two marine bands in the Vale of Neath compares favourably with the Twrch section (Ware, 1939, p. 176) where only 9 ft. of flaggy sandstones separate them. In addition to the index fossils, the *inconstans* and *reticulatum* bands of the Dinas Quarry contain *Lingula mytiloides* J. Sowerby, *Productus* sp., *Dunbarella* sp., *Nuculopsis* sp., *Orthoceras* sp., *Homoceras* sp. and *Homoceratoides* sp.

The upper part of the Basal Grit Group, including the 'inconstans' and *reticulatum* horizons, is also well exposed in the lower Pyrddin (at old quarries, three-quarters of a mile north of the Angel Hotel), near the confluence of the Pyrddin and Nedd Fechan and at Scwd-yr-Eira, a waterfall on the River Hepste. In the east of the area these highest beds are exposed at Llech Sychryd waterfall in Nant Hir, a tributary of the Cynon. A *Lingula* band in the roof of a thin coal and about 16 ft. below the top of the Basal Grit Group might be the equivalent of the *reticulatum* horizon. In this area the topmost 30 ft. of the Group, and all the Shale Group, have been mapped as Farewell Rock by the Geological Survey.

(b) **Shale Group.** Only three fossiliferous horizons—the *superbilingue* and *Anthracoceras* marine bands and the *Carbonicola* band—have been recognised by Evans & Jones (1929, pp. 167–8), and by Robertson (1933, p. 64), in the Shale Group of Craig-y-Dinas and the Sychryd Valley. The three bands containing the index species of *Gastrioceras*, viz. *cancellatum*,[1] *cumbriense* and *subcrenatum* were not found *in situ*. The tipped material (from the Pen-cae-draen Tunnel) examined by Robertson (1933, p. 65) probably came from the '*cancellatum*' horizon. This marine band was

[1] A more suitable name for this horizon would be the *Gastrioceras crencellatum* Marine Band, as that form occurs most frequently. However, the name '*G. cancellatum* Marine Band' has been used generally in South Wales and so is retained.

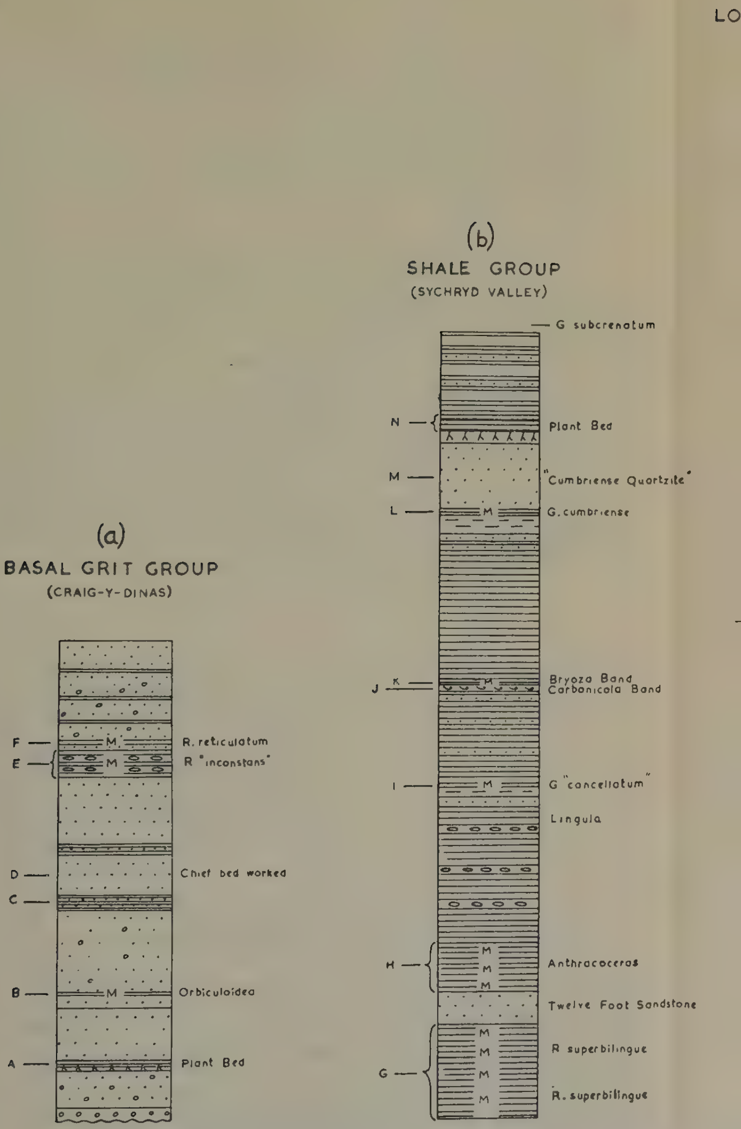

Fig. 2. Detailed successions of the Namurian and lowest Coal

noted by Robertson as occurring in the Pyrddin (1933, p. 66 and pl. IV) but was wrongly placed just above the Twelve-Foot Sandstone.

The writers have been able to determine the complete Shale Group succession in the Vale of Neath. Several marine horizons, a *Carbonicola* band and a well-marked plant-bed occur. There is only one 'mussel' band, a conclusion also reached by Ware in describing the Shale Group sequence in Carmarthenshire (1939, p. 201). The full succession (Fig. 2) can be studied in the Dinas Quarry (to the Twelve-Foot Sandstone), the River Sychryd (from that sandstone to the *Carbonicola* band) and in a tributary of the Sychryd, 200 yds. south of the Silica Levels (from the 'mussel' band to the top of the Group).

The dark blue shales (G in Fig. 2) include occasional ironstone courses and contain *Crurithyris* sp., *Nuculopsis* sp., *Metacoceras* sp. and *Reticuloceras superbilingue* Bisat. The Twelve-Foot Sandstone is a grey siliceous grit which forms a waterfall in the Sychryd. The grit is overlain by the *Anthracoceras* band (H in Fig. 2, column b), consisting of dark, thinly-laminated, iron-stained shales with *Lingula* sp., *Nuculopsis* sp., *Anthracoceras arcuatilobum* (Ludwig) and *Gastrioceras* sp. *Lingula* and *Hyalostelia* sp. occur sparsely in the upper part of the succeeding grey shales.

Bed I, a thin band of black, fine-grained, pyritic shale, is the *G*. '*cancellatum*' horizon. It is abundantly fossiliferous and the following have been collected from the numerous exposures of the marine band in the Vale of Neath:

Zaphrentis sp.
Chonetes hardrensis (Phillips)
Lingula mytiloides J. Sowerby
Orbiculoidea nitida (Phillips)
Nuculana stilla (McCoy)
Euphemites (*Euphemus*) *urei* (Fleming)
Agastrioceras carinatum (Frech)
Anthracoceras cf. *arcuatilobum* (Ludwig)
Gastrioceras '*cancellatum*' Bisat
G. *crencellatum* Bisat
G. cf. crenulatum Bisat
Homoceratoides sp.

Sporadic goniatites, lamellibranchs and small gastropods occur also in the underlying grey mudstone.

Twenty-eight feet above the *G*. '*cancellatum*' horizon there occur two feet of coarse black siltstone, overlain by one foot of grey, fine-grained, thinly-laminated shales. The Siltstone (J) is the 'mussel' band, containing *Anthraconaia* cf. *bellula* (Bolton) and *Carbonicola lenicurvata* Trueman. The overlying 'Bryozoa Band' (K) is characterised by *Fenestrellina* sp., *Rhombopora* sp., *Crurithyris* sp., *Lingula* sp., *Aviculopecten* sp. and *Nuculopsis* sp.

Fifty feet of grey shales, with some thin-bedded sandstones, separate this bed from the *G. cumbriense* marine band (L)—two feet of black calcareous shale with a thin intermediate layer of nodular ferruginous limestone. This horizon is very fossiliferous and the following forms have been collected from various exposures in the area:

Chonetes spp.
Crurithyris sp.
Lingula mytiloides J. Sowerby
Lissochonetes cf. *geinitziana* var. *senilis* Dunbar and Condra
Martinia aff. '*glabra*' (Martin)
Orbiculoidea nitida (Phillips)
Productus carbonarius de Koninck
Rhipidomella cf. *michelini* (L' Eveille)
Schizophoria hudsoni George
Spirifer spp.
Aviculopecten losseni Von Koenen
Edmondia sulcata (Phillips)
Myalina sp.
Nucolopsis cf. *laevirostris* (Portlock)
Donaldina cf. *ashtonense* (Bolton)
Glabrocingulum aff. *armstrongi* Grey-Thomas
Metacoceras sp.
Anthracoceras sp.
Gastrioceras cf. *crencellatum* Bisat
G. cumbriense Bisat
Homoceratoides divaricatum Hind

The marine band is capped by a distinctive, light-coloured quartzite—hereafter referred to as 'the *Cumbriense* Quartzite' (M). A thick fireclay separates this quartzite from the plant-bed (N), five feet of coaly shale containing *Neuropteris schlehani* Stur, *Mariopteris acuta* (Brongniart) and *Sphenophyllum* sp.

Other excellent sections of the Shale Group occur in the Vale of Neath. In the Pyrddin (below the confluence with the Nedd Fechan) the *Cumbriense* Quartzite is massive and thirty-five feet thick. The succeeding plant-bed is more arenaceous and is underlain by a rootlet ganister in which are preserved large tree-trunk sections. Good sections of the upper part of the Group are to be found along the railway and in tributaries between Pontwalby and Cwmgwrach, in Nant Gwineu and near the Dinas Powder Mills. In some localities the *Cumbriense* Quartzite trenches deeply into the underlying marine shale. The thickness of the quartzite is extremely variable, being only three feet in Nant Wyrfa.

A fairly complete succession of the Shale Group can be seen in Nant Melyn and Nant Hir, two tributaries of the Cynon. The Twelve-Foot Sandstone, seen at Llech Sychryd in Nant Hir, has contorted bedding and is separated from the top of the Basal Grit Group by only six feet of black shale containing nodules with *Schizophoria* sp. and sponge-spicules. Probably the base of the sandstone has scoured some of the underlying *superbilingue* shales. The *Anthracoceras* band is separated from the '*cancellatum*' horizon by thirty feet of grey-black shale and three feet of sandstone.

About 100 feet of measures, predominantly shales and flags, occur between the *Anthracoceras* band and the *Cumbriense* Quartzite in Nant Melyn, but the '*cancellatum*', *Carbonicola* and *cumbriense* horizons are not exposed. Probably the last-named band was eroded by the overlying quartzite, in which occur conglomeratic layers.

3. THE LOWEST AMMANIAN SUCCESSION IN THE AREA

Excellent exposures of the lowest portion of the Coal Measures are to be found within the area, particularly in the Llech, Pyrddin, Wyrfa and Cynon Valleys. Appreciable faulting breaks the continuity of the full succession in these valleys, but fortunately a complete sequence can be examined in the Gwrelech (which joins the River Neath near Glynneath) and its tributaries. Although the Gwrelech section lies just outside the limits of the area described, the writers feel that this complete (and hitherto undescribed) section should be recorded, as it provides the key for unravelling the complex fault pattern along the Pyrddin, Sychryd and upper Cynon Valleys.[1]

The Ammanian strata in the area belong to two zones:

(b) Zone of *Carbonicola communis*.
(a) Zone of *Anthraconaia lenisulcata*.

(a) *The lenisulcata zone*. The base of this zone is the *G. subcrenatum* marine horizon, while the upper limit was believed by Professor Leitch to occur just below the Cnapiog Coal. The sub-Cnapiog Coal Measures can be subdivided into two lithological divisions:

(ii) Argillaceous group: a series of shales and thin sandstones with five marine or pene-marine horizons and two *Carbonicola* bands.

(i) 'Farewell Rock': massive sandstones with occasional bands of shale, the *subcrenatum* band forming the base of the division.

(i) 'Farewell Rock'. The thickness of this division in the Vale of Neath was given as 80–100 ft. by Evans & Jones (1929, p. 166). This figure has been found to be inadequate. Again, Robertson (1933, Fig. 8, and pp. 69–70) claimed that the 'Farewell Rock' showed a marked, though gradual, westward thickening between the Taff and Tawe Valleys. Such a thickening does not occur within the described area. The division maintains a thickness of about 150 ft., from the Cynon to the Llech, and as Ware (1939, fig. 10) has shown, this is also its thickness in the Twrch.

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[1] The section is included in a full description (now being prepared for publication) of the Lenisulcata zone of the North Crop of the South Wales Coalfield, by the late Professor Duncan Leitch and the writers, who are indebted to Professor Leitch for granting permission to describe the section in this paper.

The *subcrenatum* band is exposed at Pontwalby railway station (near the confluence of the Gwrelech and Neath rivers). The dark marine shales and mudstones contain:

Derbyia sp.
Lingula sp.
Edmondia sulcata (Phillips)
Nuculopsis sp.
Schizodus sp.
Euphemites sp.
Anthracoceras arcuatilobum (Ludwig)
Gastrioceras aff. *listeri* (J. de C. Sowerby)
Gastrioceras subcrenatum (Schlotheim)

The fossiliferous horizon is succeeded by 130 ft. of massive, grey or fawn-coloured, siliceous grits with occasional bands of flagstone and shale. The full sequence is exposed in the Gwrelech gorge, beneath the viaduct. The lowest grit bed (i.e. immediately above the *subcrenatum* horizon) has a conglomeratic base. Sideritic pebbles in this conglomerate show bored structures, probably due to the action of boring worms. The upper limit of the 'Farewell Rock' is a persistent plant-bed, which here comprises six feet of sandy shales and flags, best exposed near the mouth of a small tributary on the left band of the Gwrelech (200 yds. south of the viaduct). The plants include *Alethopteris neuropteroides* Susta, *Neuropteris gigantea* Sternberg, *Mariopteris acuta* (Brongniart) and *Lyginopteris hoeninghausi* (Brongniart).

Good sections of the 'Farewell Rock' also occur in the Llech, the Pyrddin (near the Angel Hotel and at Scwd Einion-gam), the Wyrfa, the Cynon (near the Gamlyn Viaduct), Nant Melyn and Nant Hir. The best section in the Llech is at Melin-Llech, where the river cuts through 150 ft. of grits, flags and shales. Two plant-beds, about thirty feet apart, occur here at the top of the 'Farewell Rock'—these are the well-known Llech Plant Beds, described by Dix (1933, p. 797) and Robertson (1933, p. 98). They are well exposed in the high cliffs of the Llech gorge, half a mile upstream from Melin-Llech.

In the Wyrfa the 'Farewell Rock' is characterised by massive siliceous grits, but in the Cynon Valley, farther east, the sequence becomes shaly and a number of thin coals occur. The *subcrenatum* shale is at least forty-seven feet thick near the Cross Bychan Inn, in Nant Melyn. The plant-bed at the top of the 'Farewell Rock' (and overlying a thick, occasionally-pebbly, grit) is exposed on the left bank of the Cynon, 350 yds. downstream from the Gamlyn Viaduct.

(ii) The argillaceous group (above the 'Farewell Rock' and below the Cnapiog Coal). The thickness of this division varies from 140 ft. in the east of the area to 200 ft. in the west. The group contains seven fossiliferous horizons, five marine and two non-marine.

Robertson (1933, pp. 98–9) has recorded most of these marine bands in the Llech and Tawe Valleys. He stated that the marine bands 'have not been seen east of Cwm Llech' (1939, p. 92) and 'that it is not certain that the marine beds which develop westwards near the base of the Coal Measures actually come in above the top of the Farewell Rock. They are rather more likely to appear as intercalations in the highest part of the Farewell Rock of farther east, though no definite observations on this point have been made.' (1933, p. 77).

Professor Leitch and the writers have traced the marine bands along the North Crop of the Coalfield from Llandebie to Brynmawr. Between Llandebie and the Cynon Valley the marine horizons definitely overlie the plant-beds which mark the top of the 'Farewell Rock'. Moreover, the marine bands are always overlain, in the region between the Tawe and Cynon Valleys, by shales and ironstones with two distinctive mussel-bands.

The best section of the argillaceous group occurs in a small tributary of the Gwrelech (the tributary mentioned on p. 240). The section is shown in Fig. 2, marine bands being marked M_1 to M_5, and the 'mussel' bands being marked C_1 and C_2.

Horizons M_1, M_2 and M_3 are truly marine, the dark shale and mudstone containing Productids such as *Marginifera* sp. and *Productus carbonarius* de Koninck. *Aviculopecten* sp. and *Euphemites* sp. have been found in M_3. *Lingula* occurs in all except M_5 which contains only fish-fragments: west of the Tawe this fifth band also contains *Lingula*.

Each of the five marine horizons can be identified easily. A thin sandstone (the 'One-Foot Sandstone') always occurs near the top of M_1. M_2 is always underlain by a downward sequence of thin coal, fireclay and thin siliceous grit. Horizon M_3 is identified by its basal layer which contains pyritic pipes and, frequently, large *Lingula*. Perhaps the most distinctive, though often (because of its thinness) the most elusive, is M_5 which is characterised by dark shale overlying a peculiar basal rubble (seldom more than half an inch thick) of quartz granules. The granular layer contains rolled fish-fragments and scales referable to *Rhizodopsis sauroides* (Williamson), while the dark shale is overlain by very light grey shale, the colour change being frequently accentuated in the beds of streams.

The five bands occur within 100 ft. of grey and often soapy shales. These measures are separated from the Cnapiog Coal (and its underlying fireclay and grit) by fifty feet of shales in which occur numerous courses of ironstone and also two 'mussel' bands. The lower 'mussel' horizon (C_1), a dark-grey siltstone, contains *Carbonicola* aff. *limax* Wright, *C.* cf. *protea*

Wright and *C.* aff. *rectilinearis* Trueman & Weir, whilst the upper, more shaly, horizon (C_2) is characterised by *Carbonicola* aff. *communis* Davies & Trueman, *C.* aff. *crista-galli* Wright and *C.* aff. *martini* Trueman & Weir. Professor Leitch believed that the boundary between the *Lenisulcata* and *Communis* zones occurs between these two mussel-bands. Robertson has noted the occurrence of the lower band in Nant-y-Gwyddyl, on the west side of the Vale of Neath (1933, p. 97), and in the Llech (1933, p. 97).

In the extreme west of the area, the seven fossiliferous horizons can be seen in the Llech and its tributaries; especially the one which begins near Cefn Byrle Farm. The sequence in this stream has been described by Robertson (1933, pp. 97–8) but he did not record M_5 and did not suspect that M_2 was missing (through faulting) in this section. The missing portion is present in an adjacent tributary.

In the Pyrddin Valley no section of the argillaceous group has been recorded previously, but all the horizons except M_2 and C_2 have been traced by the writers. The 'One-Foot Sandstone' (M_I) forms a broad low waterfall east of Ynys-domlyd, while two tributaries to the south of this farm provide exposures of M_4, M_5 and C_I. The fourth marine band is underlain by dark-grey flags which pass downwards into flaggy, siliceous sandstone, this sandy development beneath M_4 being characteristic of areas west of the Vale of Neath. Further exposures of the marine beds occur in faulted ground in the Neath Valley, as, for example, near Ynyscymmer Farm (M_3) and near the confluence of the Pyrddin and Mellte (M_I and M_2).

A complete section from the 'Farewell Rock' to C_I occurs in Cwm Wyrfa. The 'One-Foot Sandstone' displays local thickening (up to six feet in places), while the peculiar piped base of M_3 is seen 200 yds. north-north-west of Glan-ffrwd. Horizon C_2, and the Cnapiog Coal, are cut out by the Hirwaun No. 2 Fault.

Mainly because of faulting, only M_I and C_I are exposed in the Cynon. The first marine band is seen above the plant-bed (p. 240), while the 'mussel' band is well exposed at the marked bend of the river, 300 yds. south-east of Gamlyn Farm.

(b) *The communis zone.* This division mainly comprises the measures between the Cnapiog and Bluers coals. These strata have been described by Robertson (1933, pp. 100–12) who has noted their westward thickening, from 120 ft. near Aberdare to 250 ft. at Abercrave. Therefore the writers merely wish to draw attention to some new information which has facilitated the mapping of the area.

The Cnapiog Coal is overlain by about twenty feet of shale, dark blue and fissile at first but becoming lighter upwards, with ironstone nodules. The dark shale contains fish-fragments, mainly scales, while the ironstones yield *Naiadites flexuosa* Dix & Trueman. The shale is overlain by ten to twenty feet of massive, siliceous grit which is traversed by several quartz veins and displays a peculiar ball-like structure. The grit is overlain by dark shale (with ironstones) containing *Carbonicola pseudorobusta* Trueman. These distinctive sediments have greatly facilitated the identification of the Cnapiog Coal in the Pyrddin Valley.

The remaining floral and faunal horizons occurring in the *communis* zone of the area have, however, none of the constancy and ease of identification of those found in the *lenisulcata* zone or in the Namurian. Generally the flora is scanty and of little zonal value in South Wales. Of interest, therefore, is the presence, in the Neath and Pyrddin Valleys, of plant-beds at about twenty to thirty feet above the *pseudorobusta* horizon. In Cwm-yr-Argoed, a tributary of the Neath, they yield *Alethopteris lonchitica* (Schlotheim) and *Mariopteris* spp. in abundance. In the Pyrddin they contain a more varied floral assemblage, which includes the following:

Alethopteris lonchitica (Schlotheim)
Mariopteris spp.
Neuropteris marginenervis Jongmans
Odontopteris britannica Gutbier
Sphenopteris schillingsi Andrae

This assemblage is distinctive and there seems little doubt that it lies above the *Neuropteris schlehani–Lyginopteris hoeninghausi* flora, which is typical of the *lenisulcata* zone in South Wales. The massive false-bedded sandstones which occur at Ynys-ymenyn in the Pyrddin Valley have been placed in the 'Farewell Rock' by H.M. Geological Survey. They occur just below the Pyrddin Plant Beds, however, and, on the floral evidence, should be referred to a level some 200 ft. higher in the sequence, i.e. twenty to thirty feet above the base of the *communis* zone.

4. THE PYRDDIN–UPPER CYNON FAULT-SYSTEM

The discovery of the numerous marker bands in the Namurian and Ammanian strata of the area has enabled the writers to prove the existence of a narrow zone of faults along the Pyrddin, Sychryd and upper Cynon Valleys. The zone trends WNW.–ESE. is seldom more than a mile wide (Fig. 1) and comprises a number of aligned and fairly persistent faults flanked by less persistent and rather sinuous fractures. The main fractures, hereafter referred to as the Llech, Pyrddin, Sychryd and Cynon faults, are in line with one another and may possibly be portions of one continuous fault. It has not been possible to prove this continuity, owing to lack of exposures in certain regions (for example at Coelbren) and also because of the complex structure of the Craig-y-Dinas district.

The WNW.–ESE. faults are normal fractures and have mainly southerly downthrows, though some fault-troughs also occur. The fault zone dies out at the Tawe Valley, in the west, and near Trecynon, in the east.

The Llech Fault can be seen at a marked bend of the River Llech, below Llech Bridge, and has here a throw of thirty feet. The fault, a normal one with a marked downthrow drag, can then be traced (by means of steeper dips) to Melin-Llech Farm. At the confluence of the Llech and the Cefn-Byrle tributary shale below M_3 is thrown against the 'One-Foot Sandstone', a southerly downthrow of thirty-five feet. The fault then keeps south of the Llech and must lie near the railway line, the sequence above the marine beds being incomplete in nearby tributaries. This main fracture is crossed by several NNW.–SSE. faults in the Llech Valley, but there is no evidence of lateral displacement. There may be several other WNW.–ESE. faults in this region; one such fracture was seen 300 yds. north-east of Cefn-Byrle.

Glacial drift and peat obscures the solid geology at Coelbren; but possibly the Llech Fault continues eastwards, however, to the head of the Pyrddin Valley. An aligned fracture—the Pyrddin Fault—can be detected at Ynys-ymenyn Farm (Fig. 3), bringing the sandstone which underlies the *communis* zone plant-beds against M_3, a southerly downthrow of about 100 ft. Coursing near the base of sandstone crags, to the east of the farm, this fault crosses the Pyrddin several times in the vicinity of Ynys-domlyd. At the marked bend in the river, 300 yds. east of that farm, sandstones below M_4 are faulted against the 'One-Foot Sandstone', a southerly downthrow of about forty feet. A marked decrease in the amount of throw has occurred at the junction of the Pyrddin Fault with a NNW.–SSE. fault (Fig. 3).

Other WNW.–ESE., though more sinuous, fractures can be proved in the numerous tributaries to the south of Ynys-ymenyn and Ynys-domlyd. The most important fault has a northerly downthrow of 110–140 ft., in one stream bringing the Cnapiog Coal against the fireclay of the lowest coal of the Bluers Group. A parallel fracture probably traverses the hillside north of the Pyrddin. This would explain the surprising occurrences of M_1, M_3 and M_4 on the north bank of the river and at the southern end of what appears to be a normal dip slope of 'Farewell Rock'. The southerly downthrow of this fault could be almost 100 ft.

The Pyrddin Fault cannot be traced near the Einion-gam waterfall, farther downstream, though probably it lies just south of the river. The occurrence of M_5 on the Banwen–Glynneath road, south-south-east of the waterfall, supports the existence of a fracture between that exposure and the Pyrddin. The excessive thickness of the 'Farewell Rock' in the Pyrddin, between the waterfall and Nant-y-Gwat, suggests the presence of other faults, though their trend is not known.

Again it is difficult to locate the WNW.–ESE. fault-system in the region between Einion-gam and the Sychryd. The Craig-y-Dinas district is intensely faulted, being situated on the Vale of Neath Disturbance, and a

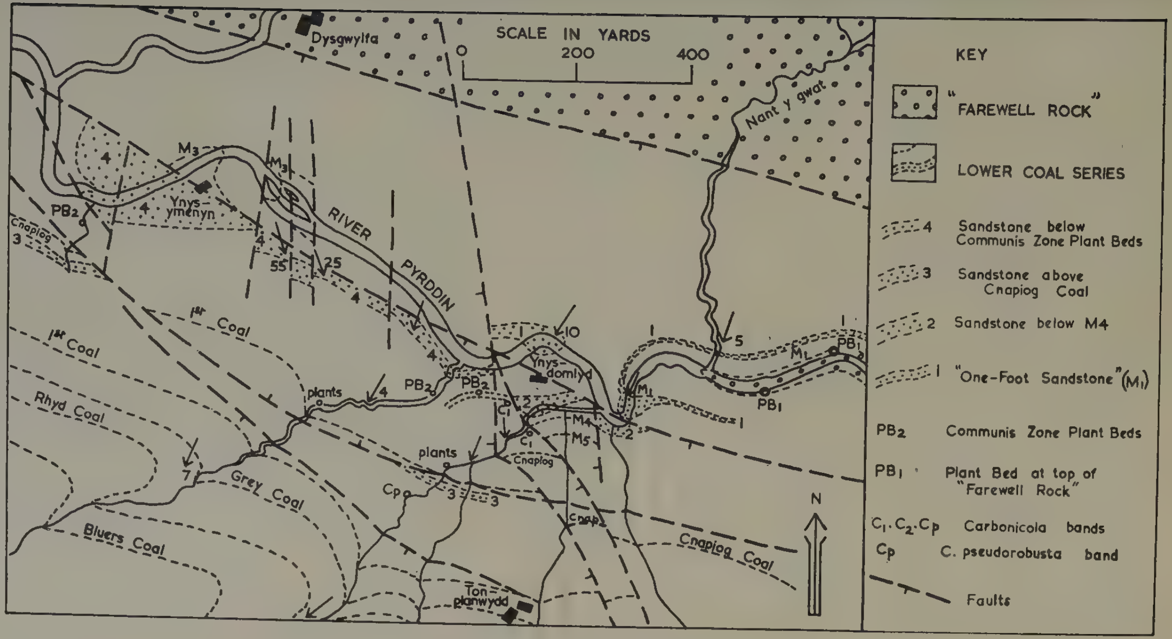

Fig. 3. The geology of a portion of the Pyrddin Valley

number of fractures could mark the continuation of the Pyrddin fault-system—for example, those occurring at the Silica Levels in the Lower Pyrddin and again in the stream near Dinas Terrace. Other WNW.–ESE. faults occur near the Dinas Silica Levels and at Ffynnon Ddu, on the western slopes of Penderyn Foel.

However, another major fracture can be located in the Sychryd Valley and crosses the tributaries on the north side of that river, near Tylemorgrug Farm. In one of these streams, the *Carbonicola* band of the Shale Group is upthrown to the north by at least thirty-five feet. Further proof of the Sychryd Fault is provided by the difference in level of the base of the 'Farewell Rock' on the two sides of the valley, the strata being almost horizontal.

Between the Sychryd and Hirwaun, unfortunately the rocks are hidden by glacial and recent deposits, but it is probable that the Sychryd Fault continues along the Camnant stream and beneath the Hirwaun ponds. As in the case of the Pyrddin Valley, there may be other parallel fractures to the north; at least three faults can be proved in the tributary that joins the Sychryd near the Dinas Silica Levels.

At Hirwaun the upper part of the 'Farewell Rock', seen at the bend of the Cynon in the district known as Tramway, is brought very close to ironstone-measures which are characteristic of the uppermost part of the *lenisulcata* zone; this suggests the presence of a fault with a southerly downthrow of at least eighty feet. Probably the marine beds above the 'Farewell Rock' are also faulted out near Parc-Hensol, half a mile to the east. These conclusions are justified by the discovery of the fracture (the Cynon Fault) in the river at a point two hundred yards south-east of Gamlyn Farm. Shales occurring between M_5 and C_1 (the *Carbonicola* band is well exposed) have here been thrown against the coarse grit which occurs near the top of the 'Farewell Rock', a southerly downthrow of seventy feet. Other parallel fractures occur in the Hirwaun district, as for example near the Gamlyn viaduct and at Cross Bychan, the latter fault probably continuing westwards to the Hirwaun Brickworks. Most of these subsidiary faults have southerly downthrows, varying in amount between ten and seventy feet.

The WNW.–ESE. faults may continue for a short distance east of the Cynon at Llwydcoed (a number of small underground faults on the Geological Survey six-inch map confirms this) but the fault system cannot be traced on Aberdare Mountain, or in the Taff Valley, farther east.

The age of the WNW.–ESE. fault-system cannot be fixed precisely. First thoughts recall faults of similar trend which were recorded by Robertson in the Merthyr Memoir (1933, p. 90). These include disturbances at Slades Patch (Hirwaun), Brynteg, Seven-Sisters and British Rhondda Colliery. However, whereas the Pyrddin–upper Cynon faults are normal fractures with mainly southerly downthrows, Robertson's examples are mainly reverse faults with northerly downthrows and are frequently accompanied by minor folds, i.e. are compressional faults. Moreover they are restricted to certain Coal Measure horizons, particularly the Nine-Feet, Six-Feet and Upper Four-Feet coals, and, as Robertson suggests, are probably intra-Coal Measures disturbances.

An Armorican age would seem more probable for the Pyrddin–upper Cynon faults, particularly as they occur in areas where the other major structural elements have been shown to be mainly of Armorican origin (Owen, 1954, p. 356). Nevertheless the writers are impressed by the lack of faults with a WNW.–ESE. trend in the northern portion of the South Wales Coalfield. This scarcity is illustrated in Fig. 4. Also it shows the much greater importance of such fractures in the southern part of the coalfield (near Maesteg) and more especially in the Vale of Glamorgan. In the Vale, WNW.–ESE. faults predominate and affect Triassic, Rhaetic and Lower Lias strata; clearly they are of post-Liassic age. They include the Penarth, St. Fagans, Cowbridge and Coity faults, the latter being a member of the important system that defines the southern limit of the coalfield. Frequently the direction of downthrow is towards the south, notable exceptions being the Cowbridge and Penarth faults. The majority of the fractures appear to be normal faults and a number of fault-troughs occur. They are of tensional origin and differ appreciably from the parallel faults of areas farther west (for example, Gower), those fractures being predominantly reverse faults (with mainly northerly downthrows) of Armorican age.

The WNW.–ESE. faults in the Vale of Glamorgan are later than, or at least as young as, the folds in the Mesozoic strata of this region. Generally the folding is believed to have occurred in Tertiary (probably Miocene) times, and the WNW.–ESE. fault-system in the Vale is probably of similar age. Among others, Strahan & Cantrill (1904, p. 90) were impressed by the unique trend and later origin of these fractures.

Similarly-trending faults predominate in the adjacent portion of the coalfield, i.e. in the Maesteg area. These fractures, too, are chiefly normal faults with sinuous courses and have mainly southerly downthrows. They appear, therefore, to be closely related to the faults in the Vale of Glamorgan, and, even though no Mesozoic deposits are preserved in the coalfield area, the writers suggest that many of the WNW.–ESE. fractures in the Maesteg region are of post-Liassic, probably Miocene, age.

A Miocene age is postulated also for the parallel Pyrddin–upper Cynon faults. This system compares more favourably with the Vale of Glamorgan and Maesteg fractures than with any others in the coalfield, and, moreover, does not appear to have been displaced laterally by the main shear fault of the Neath Disturbance. Therefore the WNW.–ESE. belt must post-date that shear, shown to be of Armorican age (Owen, 1954, p. 356).

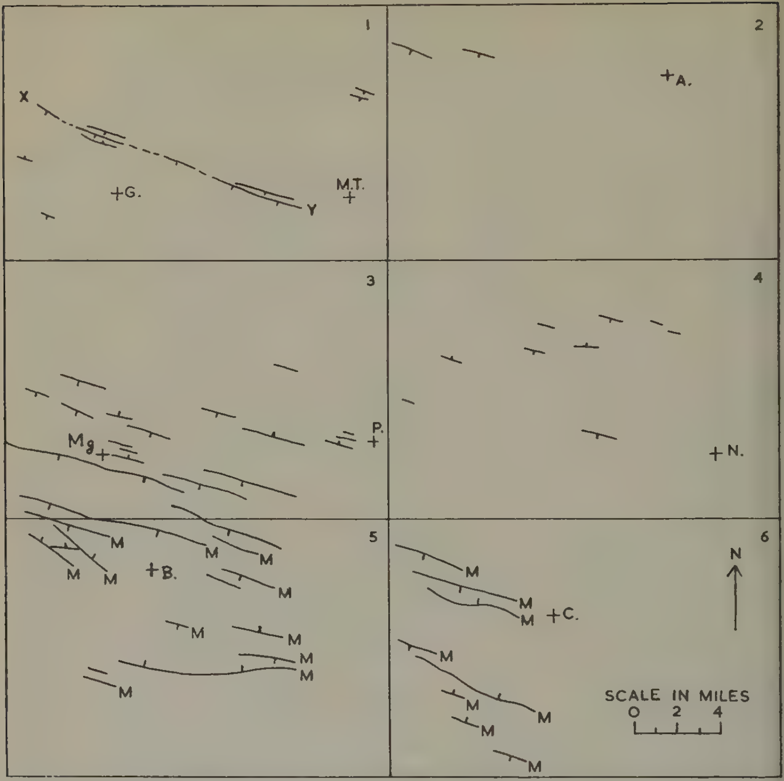

Fig. 4. The WNW.–ESE. Faults of the Vale of Glamorgan and the eastern part of the South Wales Coalfield

Faults marked M affect Mesozoic strata. The Pyrddin–Upper Cynon Fault-System is marked X–Y. The rectangles represent the boundaries of the Geological Survey One-Inch Sheets.

1. Sheet 231	2. Sheet 232
3. Sheet 248	4. Sheet 249
5. Sheet 262	6. Sheet 263

Key to towns : A. Abergavenny. B. Bridgend. C. Cardiff. G. Glynneath. Mg. Maesteg. M.T. Merthyr Tydfil. N. Newport. P. Pontypridd

Probably these normal WNW.–ESE. fractures were caused by a regional tension acting at right angles to the faults. Anderson (1951, pp. 47 and 186) has postulated that a north-east and south-west tension was operative over a large part of Britain in Tertiary times. Local variations in direction of this tension could be expected, as suggested by Anderson (1951, pp. 46 and 186), and such was the case in South Wales.

The NNW.–SSE. faults that cross the Pyrddin–upper Cynon fault-system (for example, in the Pyrddin Valley and at Hirwaun) are probably mainly of much earlier origin. Also the Tertiary tension could have caused slight renewed movements to have occurred along such fractures. Previously one of the writers suggested that posthumous movement occurred along NNW.–SSE. faults in the vicinity of the Neath Disturbance, possibly as late as Tertiary times (Owen, 1954, p. 357).

R. O. Jones (1939, p. 536) maintains that the River Cynon was once a much more important river, rising farther north and flowing for part of its course along the present Llia. He also believed that this Llia–Cynon consequent, initiated on a tilted but even surface with very little Mesozoic cover (1939, p. 556), developed (at an early stage in its history) a major tributary along the outcrop of the Pennant Sandstone (1939, p. 539). This tributary followed the course of the present Pyrddin and Sychryd rivers and had its source in the headwaters of the present-day Tawe.

The writers, while agreeing with most of Dr. Jones's ideas, suggest that the Pyrddin–Sychryd tributary developed along a narrow, but extensive, WNW.–ESE. fault-system and not merely along the junction of the Lower Coal Series and Pennant Sandstone. Moreover, they believe, that the consequent drainage was initiated on a Mesozoic cover in early Tertiary times (cf. O. T. Jones, 1951, p. 222) and that whatever remained of this cover was faulted along the Pyrddin–upper Cynon line in Miocene times. This fracturing resulted in the development of the Pyrddin–Sychryd tributary, the stream flowing initially in its lower reaches along that portion of the Cynon which today lies between Hirwaun and Llwydcoed and joining the ancestral consequent at the latter locality. At a later period some modification of the course of the Llia–Cynon river occurred, the tributary then entering at Hirwaun.

That the Pyrddin–Sychryd stream developed at a fairly early stage in the history of the Cynon is suggested by the appreciable height of the Pennant-escarpment to the south of the ancestral tributary. As O. T. Jones (1951, p. 220) has shown, any possible wind-gaps marking original southward continuations of other consequents (such as the Nedd Fechan) over this escarpment are relatively high (1800 ft. O.D. or above). These heights are far greater than those of comparable wind-gaps (500 ft. O.D.) to the south of the Amman, Lower Twrch and Gwendraeth Fawr, rivers which developed merely along the Lower Coal Series–Pennant Sandstone junction. Therefore the development of the Pyrddin–Sychryd tributary must appreciably ante-date that of the more westerly tributaries.

The postulation of a Miocene age for the Pyrddin–upper Cynon fault-system is therefore reasonable. Tertiary time would have been sufficiently advanced to have allowed time for the development of the consequent drainage and for the removal of much of the Mesozoic cover over the coalfield. Also sufficient time would remain for further modifications to the Cynon headwaters (see R. O. Jones, 1939, p. 540) before their final capture by the River Neath in later Pliocene times.

ACKNOWLEDGMENTS

The writers wish to thank Professor T. N. George and Professor Duncan Leitch for their encouragement and sustained interest in this work and for their helpful comments. Professor Leitch accompanied the writers in the field on many occasions and they are indebted to him for his valuable advice. Also the authors greatly appreciate the readiness with which Mr. W. D. Ware has placed at their disposal his unrivalled knowledge of the Upper Carboniferous floras and faunas of South Wales. Thanks are due, also, to Mr. T. C. Marchant for his kind assistance in photographing diagrams and maps.

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Minerals in the Permian and Trias of North-East England[1]

by A. FOWLER

Received 1 June 1954

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ABSTRACT: In this paper is given an account of the presence of barite, fluorite, galena and other minerals in the Permian and Trias of North-East England. The relationship of the minerals to the country-rock is described. It is shown that the Magnesian Limestone has been mineralised throughout its entire thickness. Also the origin and age of the mineralisation is briefly discussed.

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1. INTRODUCTION

A FEW YEARS AGO an account was published of the occurrence of barite, fluorite and other minerals in the lowest beds of the Permian of South Durham (Fowler, 1943, pp. 41–51). These minerals had been found in the cores of borings which were put down to prove extensions of the Productive Coal Measures under the cover of Magnesian Limestone. Since the publication of that paper, our knowledge of the mineralisation of the Magnesian Limestone has been increased as a result of information from further bores, either for coal or for water, and from the discovery of a mineralised zone in one of the South Durham dolomite quarries. This additional information is recorded in the present paper.

As a full account of the various minerals and their relationship has been given already, in the paper referred to, a more summary treatment is adopted here.

The map (Fig. 1) shows the outcrop of the Magnesian Limestone of Durham and the position of the bores and quarries in which minerals occur.

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[1] Published by permission of the Director of H.M. Geological Survey.

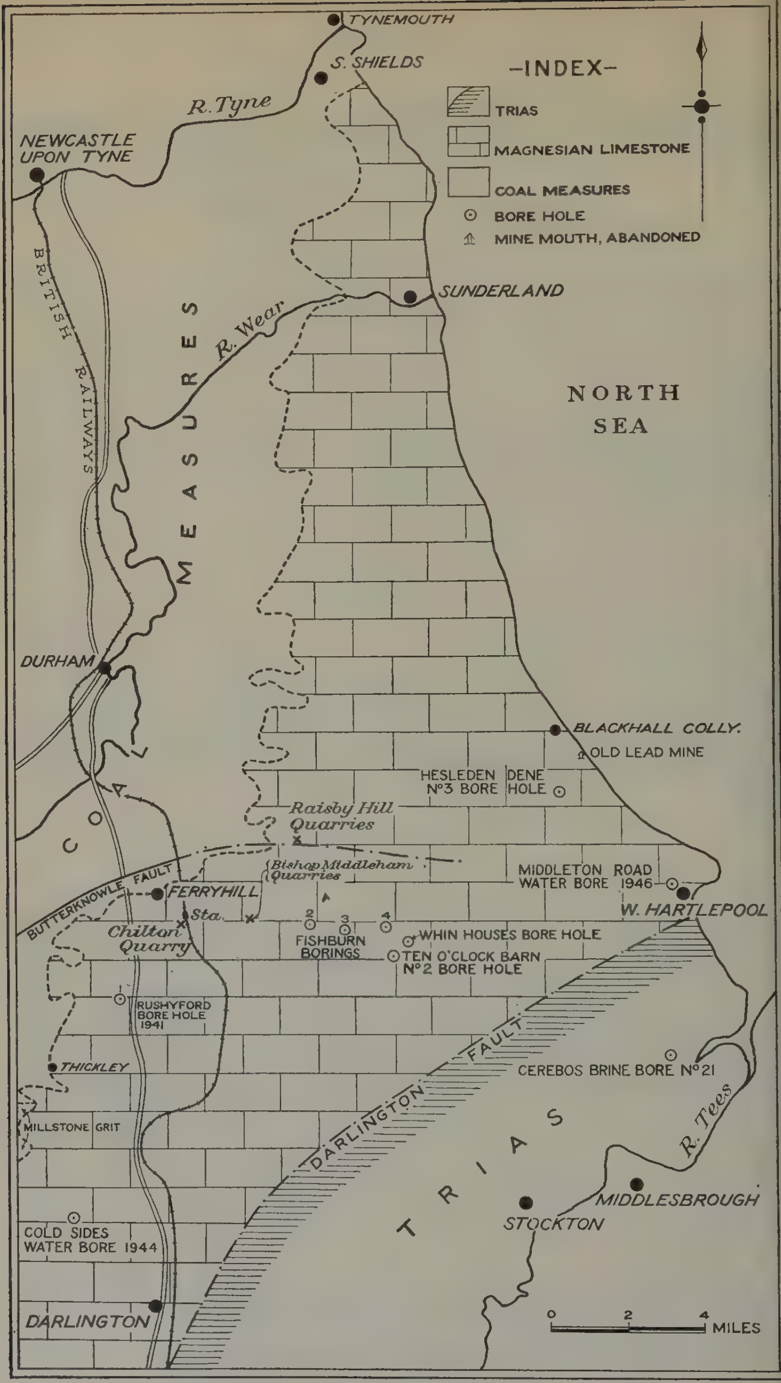

Fig. 1. Geological map of East Durham

Those bores and quarries with which this paper is mainly concerned are described below.

2. AREA NORTH OF THE DARLINGTON FAULT

(a) **Ten O'Clock Barn No. 2 Bore.** This bore, commenced in 1945, was the last of a series begun in 1939 to prove the southward extension of the Productive Coal Measures in the Fishburn area. After passing through a thick cover of glacial deposits, the bore entered the Magnesian Limestone at 262 ft. from the surface and at 519½ ft. passed into Coal Measures (Fig. 2 (A), p. 254).

The Magnesian Limestone rocks which are cut in the bore are lithologically similar to those occurring elsewhere in the district at this position in the local succession. The first 60 ft. consist of yellowish, porous, oolitic, calcareous dolomites; the remainder, save for about 30 ft. towards the base, consists of dense, finely crystalline, occasionally slightly porous, tough, grey or yellow dolomites, often with calcite veining and with cavities lined with nail-head spar. As an 18-in. bed of Marl Slate occurs at the base of the formation it is reasonably certain that here, as in the earlier Fishburn bores,[1] we are dealing with the lowest 250 ft. of the Magnesian Limestone.

Barite and fluorite were abundant in the upper part of the bore, but neither sphalerite nor galena was observed.

Barite. This mineral is present at intervals throughout the top 50 ft. of the Magnesian Limestone. It is whitish or slightly pink in colour and usually massive; also it occurs as patches and veins up to 3 in. thick, and as threads or fine ramifications. Occasionally it makes up almost the entire width of the core, which at this level is about 5 in. in diameter (Plate 9, A). A specimen from a depth of 300 ft. shows massive barite with calcite in yellow dolomite (Plate 9, B): platy crystals of the mineral also occur on and around crystals of calcite. Dr. P. A. Sabine, who examined a section (E24305)[2] cut from this specimen, reports that: 'Barite occurs both in individual tablets and in massive fibrous form. It has γ near 1.647 and α 1.638. The massive fibrous barite, which between crossed Nicols shows an anastomosing arborescent extinction pattern, in part occurs immediately next to the cavernous dolomite-rock and infills irregularities in its surface. Beyond this massive barite occur numerous slender tablets usually about 1.8 × 0.1 mm. in section, embedded in calcite and often set at right angles to the surface of the dolomite-rock. Where they adjoin massive barite they sometimes are in optical continuity with the part they touch. Only rarely do they lie along cleavages of the calcite, and it therefore seems likely that they are not of later deposition than the calcite.'

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[1] The sites of these bores are also shown on the map (Fig. 1) and the bores are numbered 1–4 as in the earlier paper (Fowler, 1943. *Geol. Mag.*, 80, p. 47).

[2] Numbers in brackets prefixed by 'E' refer to the Sliced Rock Collection of H.M. Geological Survey and Museum.

At a depth of 399 ft. a few platy crystals of barite were observed in the fluorite-zone, but otherwise barite and fluorite do not occur together.

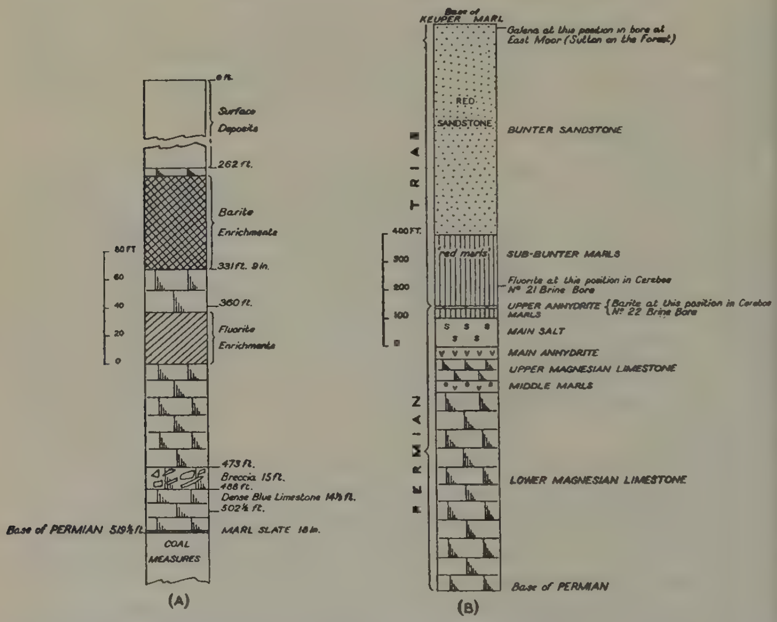
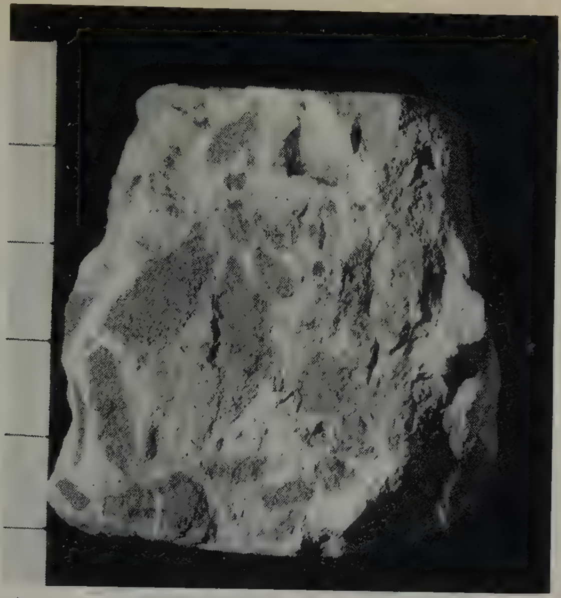
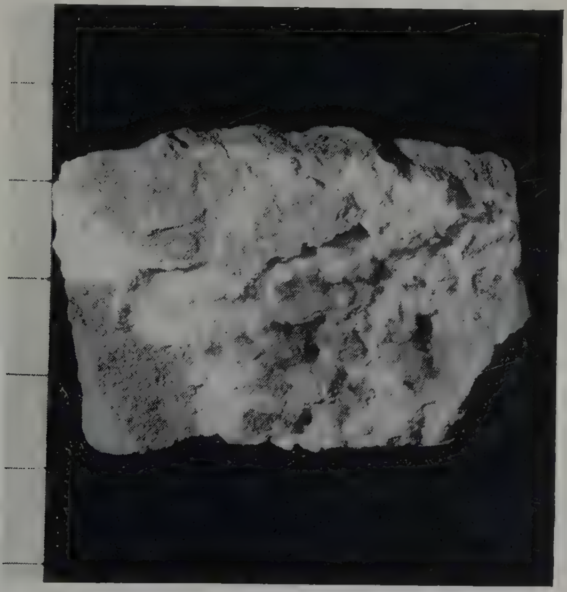


Fig. 2. (A) Vertical section of Ten O'Clock Barn No. 2 Bore
(B) Generalised vertical section of Measures in South Durham and North Yorkshire Saltfield

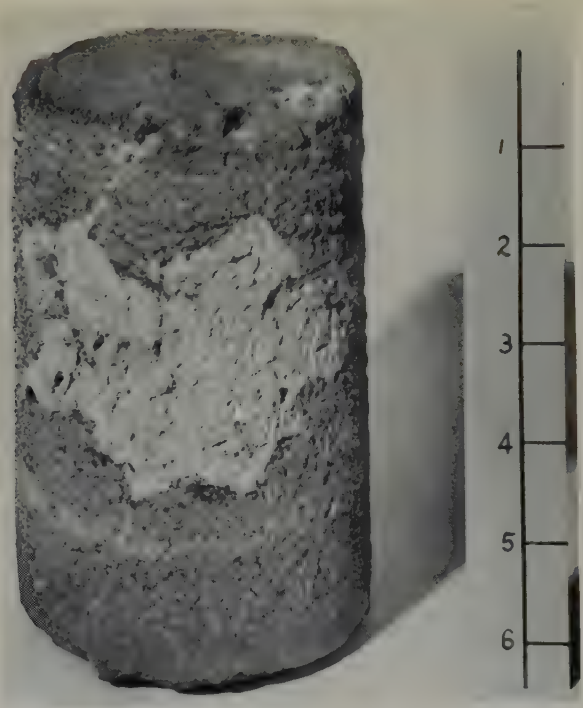
Fluorite. This mineral occurs in the bore between 360 ft. and 400 ft. from the surface as irregular patches or inclusions (Plate 10, A), and as threads and veinlets. In colour it is lightish or pale grey, occasionally with tiny specks, or spots, of a pale purple colour. In this bore it is remarkable that the massive type of fluorite, apparently replacing the dolomite, occurs to the complete exclusion of the cavity-filling crystalline variety so common in the earlier Fishburn bores. Nevertheless, in this connection, it may be recalled that in one instance at least massive fluorite was also present in one of those bores (Fowler, 1943, p. 44). As might be expected the colour of the enclosing dolomite apparently has no influence on the occurrence of the mineral which is present in grey as well as in yellow dolomite. Sometimes the fluorite accounts for almost the complete thickness of the core.



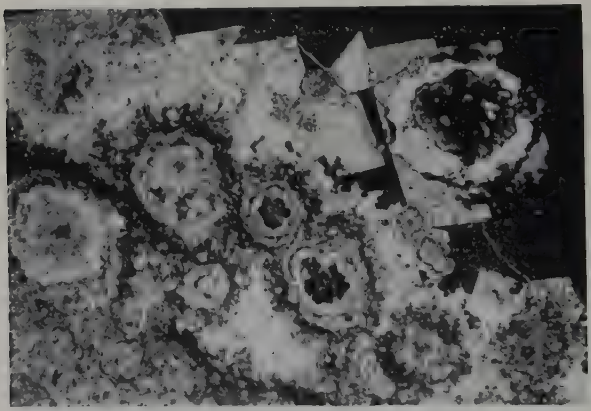
A. Barite replacing yellow oolitic dolomite. Scale of inches



B. Barite (white) and calcite (grey) in yellow oolitic dolomite. Scale of inches



A. Fluorite (white) in yellow dolomite. Scale of inches



B. Spherulitic growths of fluorite edged by euhedral fluorite. × 17

(b) **Cold Sides Bore.** The farm of Cold Sides lies a few miles to the north-west of Darlington. Here a bore for water was put down in 1944 and was taken to a depth of 108 ft. Under 18 ft. of surface deposits there was a thickness of 63 ft. of rock described by the borer as 'hard grey and brown limestone'. This rested on 2 ft. of 'black shale'. Beneath came 8 ft. of sandstone, overlying 17 ft. of 'red marl and shale'. An examination of the 'black shale' showed that it was typical Marl Slate; the underlying sandstone contained traces of plants and the 'red marl and shale' contained marine fossils. Down to the base of the 'black shale' the rocks may be assigned with certainty to the Permian: the sandstone and fossiliferous shale beneath are quite clearly of Carboniferous age.

Without doubt the 'hard grey and brown limestone' is the lowest portion of the Magnesian Limestone and does not differ from the dolomite which occurs elsewhere in the formation at this horizon; it contained whitish to pinkish massive barite as patches and inclusions, usually about two inches wide. No other minerals were observed.

The occurrence of barite here is of interest because the site is remote from the Fishburn bores and shows that the mineralisation is not confined to the country adjacent to the Butterknowle Fault. Nevertheless, a fault of considerable magnitude must pass close to the site because the record of an old well hard by does not agree with that of the present bore.

(c) **Hesleden Dene Bores.** Hesleden Dene is typical of the deep narrow valleys which are such a characteristic feature of the coastal belt of County Durham. Quite often these denes are cut through surface deposits of boulder clay and sand into underlying rock so that when not too thickly wooded they afford good natural rock-sections. Hesleden Dene enters the sea about four miles north of Hartlepool and the bores are situated about half a mile from the coast, on a small alluvial flat at the foot of the rock-cliff. They were put down between 1945 and 1946 to supplement the water supply from an earlier bore (Trechmann, 1941, p. 32). The site of No. 3 bore is shown on the map (Fig. 1): that of No. 2 bore is about 100 yds. upstream, i.e. to the west. The rocks passed through in these bores consisted of a series of soft, white, to pale creamy-yellow, grey and light-buff coloured dolomites the textures of which varied from dense to slightly porous. In No. 2 bore the first 230 ft. or so was composed of dense, grey, or blue-grey porcellanous dolomitic mudstones.[1] The most remarkable feature of the cores was the occurrence of a group of rocks consisting of thin beds of grey limestone interbedded with dark mudstone and finely-striped dark limestone bands; the latter was singularly reminiscent of the Marl Slate. This group yielded a rich and varied assemblage of marine fossils including foraminifera, crinoids, polyzoa, brachiopods, lamellibranchs and ostracods.

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[1] After exposure over several months this rock lost its dense grey porcellanous appearance and became whitish and chalk-like.

Whilst the position of these beds in the Magnesian Limestone succession is not accurately known, there can be little doubt that they lie in the upper half of the formation, and quite probably near the top of that portion.

In the bores, barite, fluorite, galena, pyrite and sphalerite and other minerals were present in varying amounts.

Barite. This mineral occurred on joint-planes throughout the complete thickness proved. As the cores were seldom less than 15 in. in diameter the joints were often quite broad and the white barite coating showed up very prominently. Usually the mineral was in the fibrous condition but when the coating had an appreciable thickness platy crystals were sometimes quite well developed.

Fluorite. This mineral was rarely obvious: small cubes occurred here and there with other minerals and a faint purple or violet colouration was observed, along with barite, in a thin crack in No. 3 bore at 212 ft. Colourless or faintly purple cubes of fluorite, averaging about 0.1 mm., together with yellow sphalerite and euhedra of galena and barite were recognised by Prof. K. C. Dunham in the heavy fraction from the washings of the scrapings from a joint-surface (Dunham, Claringbull & Bannister, 1948, p. 338).

Sphalerite. This mineral was also of rare occurrence and is present in very small quantity. Two specimens from about 250 ft. in No. 2 bore carried brown resinous-looking blende (confirmed chemically by Mr. C. O. Harvey). Of this occurrence Prof. Dunham remarked: 'The mineral is pale-yellow in powder suggesting a low iron-content, in contrast with the brown powder from the normal sphalerite of the Pennines which carries up to 3% FeS. It is translucent but isotropic as seen under the microscope.'

Galena. This sulphide was more abundant than any of the other minerals. It was particularly noticeable in the grey, highly fossiliferous marine beds, where it was plentifully scattered on joints as thin plates, films, small masses and small crystals. In a microscope slide (E121499A) of a specimen from 250 ft. in No. 2 bore, Prof. Dunham observed 'cubes of galena in the dolomite which they have presumably replaced'. The mineral appears to occur in greater quantity here than at any other horizon in the Magnesian Limestone succession of South Durham. It seems to have attracted early attention in this neighbourhood as a mile to the north-east an abandoned lead-mine,[1] marked on the six-inch field-maps of H.M. Geological Survey, shows that an attempt was made to work the ore prior to 1876, the date of the original geological survey of the district. Unfortunately we have no information as to the degree of success of the venture. The amount of galena present in the bore, whilst not inconsiderable, does not suggest that it would prove an economic proposition. But the presence of the old mine shows that mineralisation is not confined to the immediate neighbourhood of the bore. This seems to be the only instance of a trial for lead in the Magnesian Limestone of County Durham.

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[1] Doubtless that mentioned by Smythe (1923, p. 90).

Pyrite. Usually this mineral was present in greater or less amount in association with other minerals. It occurs sporadically throughout, usually in small quantity as fine granular aggregates and more rarely as crystals.

Dickite. A remarkable and a more rare occurrence, among the minerals in the Magnesian Limestone, was that of a cream-coloured, flaky, talcose-like mineral. This was observed at several levels and, like galena, was very noticeable in joints in the Marl Slate type of bed. It occurred as a coating on joint-surfaces and in one case as a thin vein cutting the cast of a shell. It has been identified as dickite, a mineral of the kaolin group. A full account of its properties has recently been published (Dunham *et al.*, *op. cit.*, pp. 338–40). According to these authors 'The dickite occurs as flakes up to 0.5 mm. diameter, some of which are aggregated into sheaf-like or radial clusters and it was not found possible to isolate a single sheaf'. Previously Dr. Phemister had concluded, on optical evidence, that dickite might be present among the minerals of metalliferous affinities already noted in the Magnesian Limestone of Durham (see Fowler, 1943, p. 44).

Collophane. A specimen of dolomite, collected by Mr. W. Anderson, from a depth of 247 ft. in No. 2 bore, contained an irregular vein up to 1 cm. wide with yellowish sphalerite and a brown resinous-looking mineral which proved to be a phosphate, identified later as collophane. An account of this mineral and its properties has recently appeared (Dunham *et al.*, *op. jam cit.*, p. 340). Whilst this seems to be the first record of the presence of this mineral in the Magnesian Limestone of County Durham, it is unlikely that its occurrence is unique since unless special search were made, a mineral present in such small quantity might easily be overlooked.

(d) **Middleton Road Bore (West Hartlepool).** This bore was put down in 1946 at the Water Works for the West Hartlepool Water Company. From a geological point of view it was not a very satisfactory bore since the rocks penetrated were too soft to give good cores. In consequence, core-recovery was poor and fragmentary. As in the Hesleden Dene bores, barite was found to be present as a thin encrustation or coating on joints at various levels. No other minerals were observed but fluorite had been noted already by Dr. Trechmann in the cores of an earlier bore hard by, for he records 'Pieces of pisolite made up of large, flattened, distorted, or broken, oolitic structures, filled or partly impregnated with clusters of brown or violet fluorite'. About three-quarters of a mile to the north-west of this bore he also recorded 'brown, and violet-coloured fluorite crystals which fill the pisolites and line small cavities', in dolomite between 180 ft. and 197 ft. from the surface (Trechmann, 1941, pp. 319–21). Moreover, in a water-bore in Villiers Street, West Hartlepool, the beds from the surface down to 144 ft. were also fairly rich in irregular grains of fluorite and, to an even greater extent, with a mineral which Dr. Phemister thinks must be blende (see Fowler, 1944, p. 201).

The rocks outcropping in the West Hartlepool area are the highest in the Magnesian Limestone north of the Darlington Fault, and whilst their exact stratigraphical position is not known precisely, they appear to be about 800 ft. above the base of the formation.

(e) **Chilton Quarry.** So far, our knowledge of minerals in Permian Strata has been derived solely from the examination of cores of borings, but during a visit to Chilton Quarry, in 1943, it was noticed that in places the rock was highly mineralised. This discovery provided an unexpected addition to our knowledge and enabled us to realise more completely the extent and manner of the mineralisation that has affected the Magnesian Limestone.

Chilton Quarry lies towards the western edge of the Magnesian Limestone outcrop and not far south of the Butterknowle Fault. The site is a few hundred yards south of Ferryhill Station, where the bottom beds of the Permian are well displayed.

The rocks quarried here are dolomites or calcareous dolomites. A nearby shaft to Coal Measures reached the base of the Magnesian Limestone at 126 ft. so that here, as in the Ten O'Clock Barn No. 2 Bore and the earlier Fishburn bores, we are dealing with the lowest beds of the formation.

The present working face extends in a roughly east and west direction for about 350 yds. An average height is about 50 ft., including the loading-bench which is about 10 ft. high.

Barite. This mineral is scattered sporadically throughout, although sometimes it is more concentrated at some localities than at others. The mineral which is massive, usually slightly pink in colour, occurs as thin lenses, rarely more than 6 in. long and up to 3 in. thick, as balls and nodules up to 4 in. across, as stringers, veinlets, threads and fine ramifications. At the west end of the quarry, in a face measuring about 30 ft. by 30 ft., patches of barite up to 6 in. long and 3 in. wide are spaced throughout at intervals of about 9 in. laterally and 6 in. vertically. Sometimes a thin skin of barite is seen to coat joint-faces. In one place, a fault or line of crush (2–12 in. wide) dipping about 45° SW. and striking approximately NW.–SE., contains veinlets and threads of barite and quite clearly has provided a path for mineralising solutions. The mineral also occurs plentifully in abandoned parts of the quarry and at intervals on the floor of the quarry there are large heaps of boulders discarded as useless for burning because they contained so much barite.

Unfortunately the mode of occurrence of the barite makes extraction impossible: had the mineral been concentrated in veins, it might well have proved an economic proposition.

Fluorite. This mineral is not so abundant in this quarry as is barite and appears to be more concentrated towards the west end of the face. It was most noticeable in the loading-bench where it was seen to be plentifully distributed over a distance of 35 yds. It occurs mostly as thin lenses averaging 2½ in. in length, and as roughly circular nodules up to 1¼ in. in diameter: a pear-shaped inclusion was 2 in. long by one inch at the broadest part.

Nearly always the mineral is massive, glassy and rather dark. An almost circular specimen about 5 in. by 4 in. showed glassy fluorite in contact with a 'grey rock' thought to be another variety of the mineral. Subsequently this was examined microscopically by Prof. Dunham who reported as follows: 'The grey rock is fluorite crystallised in what appear to be spherulitic growths, though, owing to the fact that fluorite is isotropic, the exact disposition of the crystals is difficult to follow. However, spherulite-like areas in the fluorite are outlined in yellow (? limonitic) inclusions. The spheruliths range from 1.0 to 1.5 mm. in diameter, and enclose scattered small rhombs of carbonate. This texture in the fluorite could be inherited from a 'concretionary' texture in the dolomite, if fluorite has replaced dolomite here. On the other hand, the remaining dolomite gives little indication of such a texture. Fluorite also crystallises in radiating form in such occurrences as the 'Blue John' of Derbyshire, so the texture could well be a primary one. Beyond the spherulitic region, the fluorite becomes clear and free from inclusions, and presents euhedral faces towards later fibrous barite.' A photomicrograph[1] of this slide (E24106) is shown in Plate 10, B. This grey rock resembled dolomite and is reminiscent of the 'horny-textured' fluorite, observed in some of the earlier Fishburn bores, of which it was remarked that owing to the lack of distinction between it and the surrounding dolomite 'this variety may be commoner than we suspect' (Fowler, 1943, p. 44).

Occasionally pale amber-coloured fluorite occurs in open cavities presenting good crystal faces towards the inside of the cavity. Very rarely fluorite and barite occur in contact: fluorite then presents euhedral faces towards barite. A specimen examined by Prof. Dunham shows 'Pale amber-coloured fluorite presenting euhedral faces towards pinkish yellow fibrous barite. A veinlet of calcite cuts both minerals. As the fluorite is not euhedral towards the surrounding dolomite, it may safely be concluded that it crystallised in an open cavity, and was covered by barite.'

Galena. At present this mineral cannot be seen in any part of the quarry but workmen informed me that it was obtained here in 1927 and was then used for wireless sets. As the crystal set was still in vogue at that time there is no reason to doubt the information. One workman also mentioned that when he worked in Bishop Middleham quarry in 1929, a 2-in. vein of 'lead' could be followed for 6 ft. from the bottom of the face.

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[1] Taken by Mr. Rhodes, H.M. Geol. Surv. & Museum.

Sphalerite. During one visit to Chilton Quarry, workmen produced for examination two specimens about an inch or so across and about half an inch thick which had evidently been retained as curiosities. One specimen was a fragment of dolomite enclosing pale-yellow sphalerite: a thin layer of calcite separates the mineral from the surrounding dolomite. The other was a fragment of barite and sphalerite. The sulphide was over an inch wide and pale yellow to pale brown in colour. Two veinlets of calcite cut the barite but apparently not the sphalerite. This latter specimen is in the collection of H.M. Geological Survey and Museum and is numbered MR18600.

Limonite. Small crystals of a black mineral were observed in some specimens. This was identified by Prof. Dunham as limonite (probably crystalline goethite): usually it is pseudomorphous after pyrite. This mineral had been noted in dolomite at comparable levels in the earlier series of bores.

3. AREA SOUTH OF THE DARLINGTON FAULT

So far there have been few opportunities for examining the Magnesian Limestone which underlies the salt-anhydrite deposits of the South Durham saltfield since bores rarely penetrate the main mass of the Magnesian Limestone, save in exceptional cases. Fluorite and barite have been found in rocks overlying the main salt-anhydrite bed, however. The succession in this area is shown in the generalised vertical section (Fig. 2 (B), p. 254). It will be observed that a series of 'red marls' intervenes between the Upper Anhydrite and the overlying mass of red sandstone (Bunter Sandstone). Examining a specimen[1] (Slide No. 205005) of a sandstone–mudstone–siltstone rock collected by the writer from Cerebos Brine Bore No. 21, Dr. Phemister reported as follows: 'In the sandstone bands spaces filled with gypsum are common and fluorite grows on the sandstone walls of the spaces, presenting idiomorphic outlines to gypsum. Fluorite also appears to be abundant in the cement along with gypsum.' Commenting further on this specimen Dr. Phemister remarks that 'fluorite is present in abundance and its relations indicate it was an infiltration into the cement, probably contemporaneous with the beginning of the gypsum infiltration'.

The gypsum in these 'red marls' is secondary and, without doubt, has been derived from the underlying 'Upper Anhydrite' the top of which is always gypseous. At what period in geological time this hydration occurred is not known, but it is unlikely to have occurred before the rocks had reached their present level and so came within reach of meteoric waters:

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[1] The specimen occurred at 845½ ft. from the surface and about 68½ ft. above the top of the Upper Anhydrite.

and the fact that rarely more than 6 in. of the 'Upper Anhydrite' has been transformed into gypsum might suggest a fairly recent period in geological time.

In an adjoining bore—Cerebos Brine No. 22—barite occurs with gypsum in a specimen from the 'Upper Anhydrite'. In this bed there is a peculiar band which consists of small areas of crystalline and microcrystalline anhydrite or gypsum enclosed within a meshwork of dolomite: associated with it are thin laminated layers of very dense dolomite or dolomitic mudstone. The specimen examined came from such a band and was a pale purple microcrystalline rock, banded with laminated dense dolomite. Dr. Phemister's description is as follows: 'In thin section (E20638–9) the microcrystalline rock is a turbid aggregate of dolomite in which it is difficult to distinguish the grains as individuals owing to their confused extinction between crossed nicols. They appear to have a grain size of 0.1–0.2 mm. Irregular gypsum-filled spaces are numerous in the dolomite matrix, and reach 1.5 mm. in length. In adjoining spaces the gypsum is optically continuous and this continuity has been observed over a distance of 4 mm. Inside and adjacent to the gypsum the dolomite is recrystallised in water-clear rhombs. Occasional grains of barite (not checked by individual test) are present among the dolomite and one large crystal of this mineral was seen within a gypsum area.'

For one reason or another our knowledge of the Permian rocks in the district to the south of the River Tees is very scanty and, so far as I am aware, such minerals as we have been considering are known only from a few localities.

Galena, quite obviously not detrital, was present as films and thin plates in the Permian 'basal sands' in a bore at Scorton[1] (Fowler, 1945, pp. 245–50). This bore, it may be recalled, is situated on an important east–west Carboniferous fold known as the Middleton Tyas Anticline. On the crest of this structure, and a little to the west of the village after which the fold is named, there are a number of disused copper mines that were working in the latter half of the eighteenth century (Raistrick, 1936). Hard by, malachite and azurite were noted by the writer in a bore (1941) at Violet Grange (near Scotch Corner), which lies about four miles to the north-north-west of the Scorton bore. These copper minerals, be it said, are in Carboniferous rocks whilst the galena is in the Permian, and though there is nothing, except the close proximity of the occurrences, and the fact that the localities are on the same fold, to suggest a possible origin from the same mineralisation, it should not be forgotten that chalcopyrite was found by Dr. Smythe in the basement beds of the Permian in a dolomite quarry at Piercebridge, six and a half miles north of Scotch Corner (see Fowler, 1943, p. 48), and is said to have been present in quarries at Raisby

[1] About ten miles south-south-west of Darlington.

Hill, County Durham (Smythe, 1929, p. 13; Dunham, 1934, p. 712; Fowler, 1943, p. 49).

About eighteen miles east of the Scorton bore galena, blende, fluorite, barite, and celestine were noted, in the Magnesian Limestone of the Gulf Exploration Company's Cleveland Hills No. 1 Bore (Fowler, 1944, pp. 200–1 and footnote). Still farther east fluorite, as well-formed crystals, was present in cavities in the Magnesian Limestone of the D'Arcy Exploration Company's Eskdale No. 2 Bore,[1] near Whitby.

Long ago celestine had been observed by Sedgwick (1835, p. 115) in the Magnesian Limestone around Knaresborough and Ripon in Yorkshire. He also mentions its reported occurrence near Hartlepool. Mr. T. Deans informs me (*in litt.* 18 April 1950) that he found the mineral at several localities along the outcrop of the Magnesian Limestone. Such numerous and isolated occurrences at localities far removed from salt-anhydrite fields favour an epigenetic rather than a syngenetic origin. This view receives much support from Dr. Smythe's statement that 'celestine has been found at Daddry Shield, near St. John's Chapel, Weardale, and also in Swaledale, at the Old Gang Mine. In each case the mineral (the Water Spar of Swaledale) occurs in a vein carrying galena and is colourless [as it is in Cleveland Hills No. 1 Bore] whereas the typical celestine, as the name indicates, is blue' (Smythe, 1922, p. 114).

The only other instance known to me of the occurrence in North-east England of minerals in rocks at a higher stratigraphical horizon than any so far mentioned was in a bore (1943) examined by the writer at East Moor, near Sutton on the Forest, about eight miles north of York. Here galena, as films and plates, was quite noticeable, along with abundant pyrites, in the joints of a greenish sandstone immediately underlying the base of the Keuper Marl.

4. MINERAL OCCURRENCES AND ORDER OF DEPOSITION

The chief minerals are fluorite, barite, calcite, galena and sphalerite: minerals present in subordinate amount include celestine, pyrite, limonite and dickite.

Fluorite and barite seem to be most abundant in the lowest part of the Magnesian Limestone. Although not mutually exclusive, these minerals tend to occur separately; fluorite then occurs slightly below barite.[2] When they are in contact, as occasionally happens, fluorite often presents euhedral faces towards barite and thus appears to be the earlier-formed mineral. This accords with the habit of the minerals in the Pennine country (Dunham, 1934, p. 709).

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[1] This and the Cleveland Hills No. 1 Bore would lie on the continuation of the Middleton Tyas Anticline if this latter maintained its easterly trend from Scorton as a major tectonic structure.

[2] A similar relationship is known in the Pennines (Dunham, 1948, p. 98).

Galena and sphalerite are present throughout the complete thickness of the Magnesian Limestone (800 ft. or thereabouts), whilst the former is known to occur as high as the base of the Keuper Marl. As yet there is no evidence concerning the order of deposition of these minerals relative to each other or to barite and fluorite. Examination of specimens of blende from Chilton Quarry seems to suggest that this sulphide is later than both barite and calcite. But the evidence is by no means conclusive.

Information regarding the deposition of calcite is rather conflicting. On occasion it appears to have been formed before fluorite and barite; at other times it is clearly later than barite, which it partly replaces.

Unfortunately precise information as to the paragenetic sequence of the minerals in the Permian is still very meagre and there is no evidence at all as to the order of appearance of the subordinate minerals.

5. ORIGIN OF THE MINERALS

The presence of well-formed crystals of fluorite in cavities; the replacement of dolomite by barite, fluorite and galena; the occurrence of barite in a fault or crush, and of minerals in joint-planes and veinlets are all in favour of an origin from mineralising solutions. Other workers in this field have expressed the same opinion (Trotter, 1944, p. 220). Prof. Dunham, who has studied many mineralised specimens from Permian rocks, states quite categorically that the mineral occurrences are clearly epigenetic in origin (Dunham, 1952, p. 4).

Recently, a syngenetic origin for galena and blende in the Marl State has been claimed by Deans (1950, pp. 347–8). He suggests that the metals were precipitated with, or within, the rock-forming mud and later transformed into sulphides. Lateral secretion is then invoked to account for the minerals in fissures and joints. Whilst such a process may account for some of the sulphides in the Marl Slate it would not account for these and other minerals at so many levels throughout the main mass of the Magnesian Limestone.

6. MINERALISATION

It is now quite clear that the mineralisation which has affected the Permian and overlying rocks is much more significant and impressive than was thought to be so, formerly. The difficulty of relating it to that of the Pennines, on the ground of the apparent difference in habit of fluorite, seems to have been resolved. The 'horny' variety of that mineral in the dolomite of the Fishburn bores (Fowler, 1943, pp. 44, 50) is now seen to be comparable with the massive type noted in Ten O'Clock Barn No. 2 Bore and in Chilton Quarry, and this variety is common enough in the Pennine orefield. So that with regard to the assemblage of minerals and their habits, there now appears to be sufficient evidence for relating the mineralisation of the Permian rocks to that of the Pennines.

A notable point is the complete absence in the Permian rocks of such thick workable veins and deposits as those which made the Pennine ore-field so valuable. This seems all the more puzzling as dolomitic limestones are considered to be 'favourable' rocks. It is suggested, albeit with some diffidence, that a possible explanation of this might well be the porosity of so much of the Magnesian Limestone, coupled with the presence of countless cavities and fine ramifying cracks. Rock-conditions such as these might permit the solutions to dissipate their minerals, laterally as well as vertically, through great masses of rock, instead of concentrating them in well-defined channels. On the other hand, many writers consider permeability of the dolomite to be favourable to replacement by mineralising solutions.

It may be stressed, however, that in these Permian limestones there are no impervious layers, comparable with the shale beds of the Pennines or the 'toadstones' of the Derbyshire limestone massif, to control ore deposition. In the Permian the mineralisation is widespread and disperse whereas in the Pennines it is confined and concentrated.

It is not yet clear if any significance should be attached to the fact that the majority of the mineralised localities so far noted lie near major dislocations which might have provided access for the mineralising solutions. As can be seen from the map (Fig. 1) many of the localities are in the vicinity of the 'Butterknowle Fault', an important post-Permian dislocation. Moreover, the mineralised Marl Slate at Cullercoats, Northumberland, lies alongside the 'Ninety Fathom Dyke', also a post-Permian disturbance and one of the major faults in the Northumberland coalfield: hardby is the 2-ft. band of barite noted in 1910 by Dr. Smythe in a Magnesian Limestone quarry at Marden (Smythe, 1922, p. 93).[1] As already mentioned, the dolomite which carries barite at Cold Sides also lies close to a fault.

7. AGE OF THE MINERALISATION

The evidence as to the age of the Pennine mineralisation has been discussed very fully by Prof. Dunham (1948, p. 119). But, in this connection, it should be remembered that, so far as the Magnesian Limestone is concerned, there was then evidence of mineralisation only in the lowest beds of the succession.

From tectonic and other consideration Dr. Trotter has claimed a Tertiary age for the Alston Block [Pennine] mineralisation (1944, pp. 223–9) to which he also relates these Permian enrichments.

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[1] Dr. Smythe's sketches on his copy of this paper, which he kindly sent to me, show that the barite lies along the junction between lower bedded limestones and overlying 'brecciated limestone'. They also reveal that Dr. Smythe considered the possibility of the 'brecciated limestone' and the underlying barite transgressing across the lower bedded limestone. Mineralising solutions may well have gained access along such an unconformable junction.

As it now appears certain that the mineralisation which has affected the Permian and overlying rocks is part of the Pennine mineralisation, it follows from the foregoing account that the age of this must be post-Permian and from the evidence available in North-east England, most probably post-Triassic.

The most reasonable conclusion is that the mineralisation occurred in Tertiary times which in Britain, as elsewhere, was a period of great crustal movement and intense vulcanicity.

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The Geology of South-West Jersey, Channel Islands

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Received 7 July 1954; read 4 February 1955

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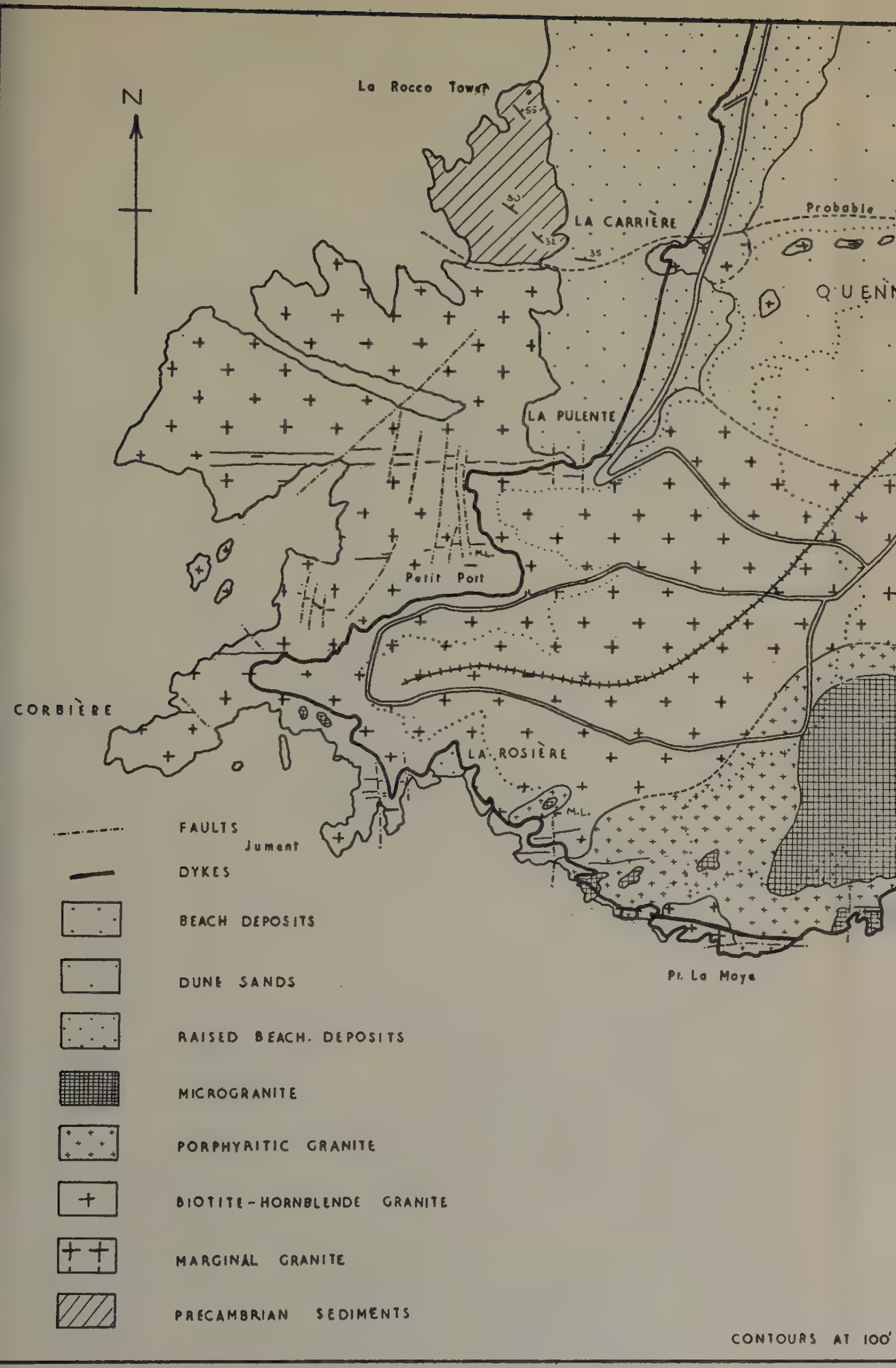
ABSTRACT: South-west Jersey is formed of a granite complex emplaced in sediments of presumed Pre-Cambrian age. The granites, considered to be Armorican in age, are of four main types: (i) The marginal facies of an older medium-grained biotite-hornblende granite in contact with the sediments of the St. Aubin area; (ii) the older biotite-hornblende granite which extends from Corbière to Noirmont; (iii) a younger microgranite occupying the approximate centre of the area and (iv) a porphyritic granite surrounding the younger granite mass. Basic dykes of various ages traverse Pre-Cambrian sediments and granites alike in north–south and east–west directions. Mica lamprophyres are distributed sporadically.

In the St. Aubin area the fine-grained marginal granite, characterised by its variable porphyritic texture and its contamination by the sediments, forms three lobes in slightly indurated Pre-Cambrian sediments. At Belcroute Bay, the type locality, the marginal granite is over a hundred and forty yards in width, but at La Carrière, in the north-west, it is only a few feet in width. The degree of contamination in the marginal granite decreases away from its contact with the Pre-Cambrian. The former is characterised by crystalloblastic textures; porphyroblastic oligoclase, perthite and quartz are commonly developed, and there is considerable micro-brecciation.

Sedimentary xenoliths are abundant in the marginal granite and common in the main biotite-hornblende granite. Large xenoliths of altered Pre-Cambrian sediments, orientated approximately east–west, occur in a few localities. The origin of such xenoliths, and of other xenoliths within the granites, is discussed.

The porphyritic granite, which is extremely variable in composition and texture, is considered to be altered older granite surrounding the younger microgranite masses.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LA CARRIÈRE
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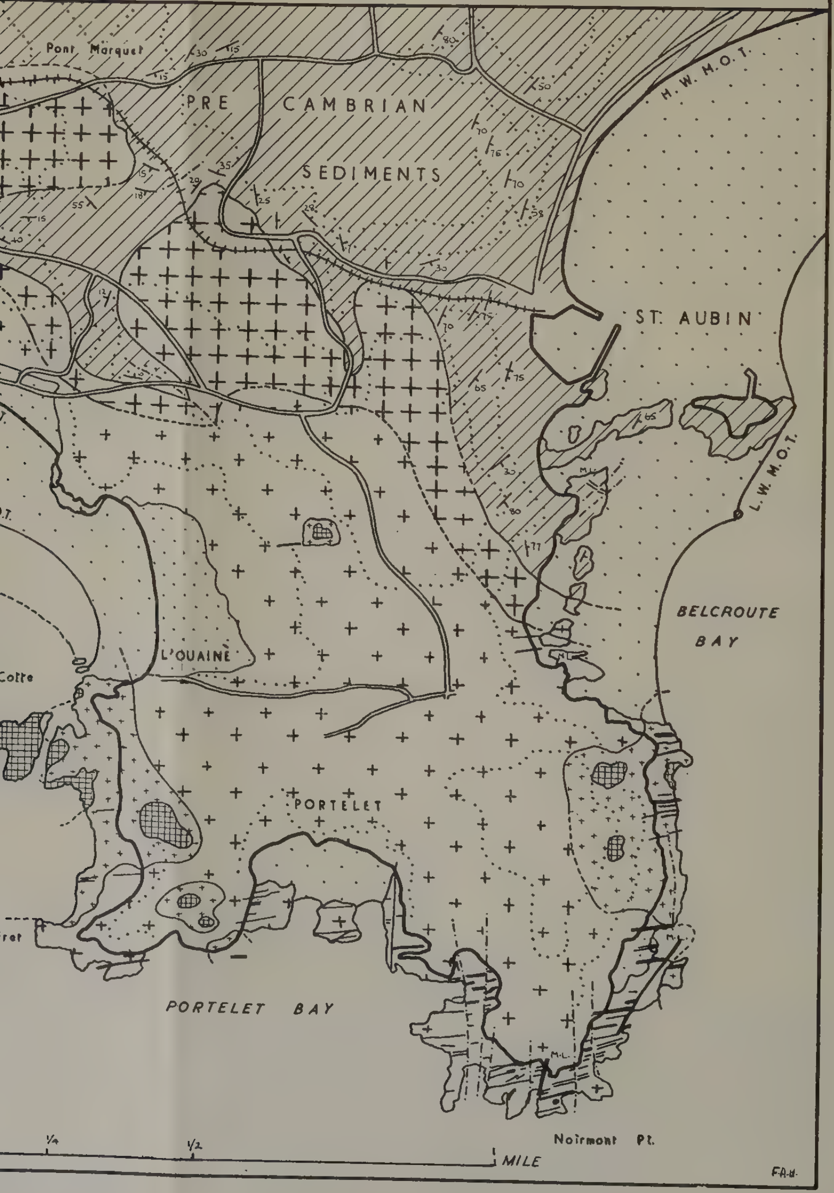
M.L.
Jument
Pt. La Moye
FAULTS
DYKES
BEACH DEPOSITS
DUNE SANDS
RAISED BEACH DEPOSITS
MICROGRANITE
PORPHYRITIC GRANITE
BIOTITE-HORNBLENDE GRANITE
MARGINAL GRANITE
PRECAMBRIAN SEDIMENTS
CONTOURS AT 100'

GEOLOGICAL MAP OF SOUTH WEST JERSEY



[*To face p.* 266

Micrometric and textural analysis of un-orientated specimens collected along traverses across the porphyritic granite (from the microgranite to the older granite) have revealed zoned variations in composition and replacement textures. The extent of alteration in the older granite round cupolas and domes of microgranite has been found to depend mainly upon the size of such microgranite masses. These zonal variations, which have been found both vertically and horizontally round a small microgranite mass at Portelet, are considered to be the result of cyclic metasomatism, both during and immediately after the emplacement of the microgranites.

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1. INTRODUCTION

PHYSIOGRAPHICALLY, the area described in this paper is the granite bastion of south-west Jersey as shown in Fig. 1. This jutting promontory partly protects from the sea the relatively softer Pre-Cambrian sediments lying to the north. Differential erosion in granite and sediments has resulted in two extensive bays to the north and east of the granite respectively. The main topographical feature is the 200-ft. Pleistocene platform which is dissected by two small east-flowing streams. The larger of the latter enters the sea at St. Aubin; the smaller at St. Brelade.

From St. Aubin to La Carrière the coastal exposures are magnificent,

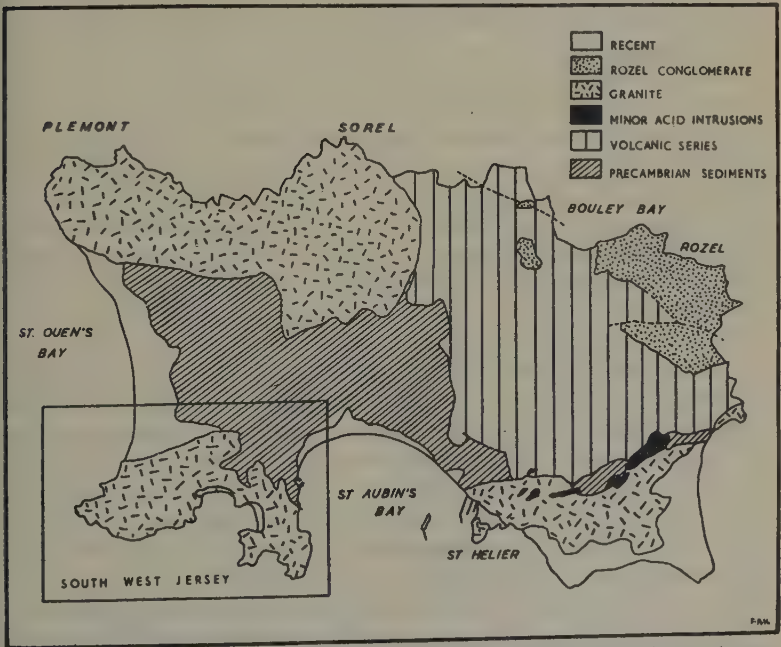

Fig. 1. Outline geological map of Jersey showing the relationship of the south-west area to the granites of the northern part of the island and the volcanic suites of east Jersey

especially in the off-shore reefs on the west coast. Inland, the exposures are less striking, since thin 'limon' deposits on the Pleistocene platform partly conceal the solid geology. At Blanches Banques, in the north-west, extensive sand dunes occur.

The granites, which are considered to be of Armorican age, are emplaced in sediments of presumed Pre-Cambrian age. Two main types occur: an older medium-grained biotite-hornblende granite and a later microgranite, the latter occupying the approximate centre of the area. In outcrop the younger granite is roughly elliptical, with the major axis of the ellipse WNW.–ESE. In the St. Aubin area a contaminated marginal facies of the older medium-grained granite occurs, whilst porphyritic granite surrounds the main microgranite mass and its many cupolas and domes. The porphyritic granite, which is only found in association with the microgranite, is considered to be altered biotite-hornblende granite.

In addition to these plutonic rocks the area contains basic dykes of three ages: (i) an early east–west series which occurs both in the reefs west of L'Oeillère and at St. Aubin; (ii) the main east–west dyke swarm exposed in the eastern part of the area, and especially in the coastal section from St. Aubin to Noirmont Point, and (iii) a few north–south basaltic dykes, in the centre of the area, at Beau Port. Mica-lamprophyres are distributed sporadically in all areas.

2. HISTORICAL REVIEW

The earliest recorded work is that of McCulloch, who described the granites of north-west and south-west Jersey in 1811, and discussed their relationships to the sediments which divide them. In 1829 Nelson made the first geological survey of the island, but no map accompanies this work, however. Nelson described the granites, recognised their intrusive character and accurately described the contact between granite and sediments in the valley west of St. Aubin.

The first significant contribution to the petrology of the rocks of Jersey was by De Lapparent, who published the first of his many papers on the volcanic rocks of the island in 1884. Two years later the Rev. Charles Noury published his survey of Jersey on the accompanying map of which the junction between the sediments and granite of south-west Jersey is accurately drawn. He distinguished a light-coloured fine-textured granulite from a coarser-grained granite. On his map the granulite is shown as extending from St. Aubin to Belcroute Bay, as well as in the La Moye area. In the present work the granulite of the St. Aubin area is regarded as a contaminated marginal facies of the biotite-hornblende granite. The granulite of La Moye, which is very different from that of St. Aubin, is now considered to be altered biotite-hornblende granite surrounding the younger microgranite. This was not recognised by Noury. With the exception of a few thin ones, Noury mapped all the basic dykes appearing in the coastal section from St. Aubin to Noirmont Point.

It was not until 1891, however, that the first petrological description of the granites was published by Boerlage. One chemical analysis—that of granite from St. John's, in the northern part of the island—is reproduced (p. 287). At the end of last century Parkinson also published his researches on the plutonic rocks of the north and south-east coasts. However, these are concerned mainly with the 'differentiation series'.

In the years immediately after the first World War, Plymen published a number of papers on the geology of the Channel Islands, in one of which he described briefly the granites of south-west Jersey and distinguished the microgranite of Beau Port from the granites of Portelet and Corbière. Plymen considered that these granites, like the sediments, are Pre-Cambrian. On the other hand, Groves, Mourant, Wells and Wooldridge consider that some of the plutons are of Armorican age.

3. FIELD RELATIONS

(a) **Pre-Cambrian Sediments.** The sediments have been variously described as shales, greywackes and phyllites. In the past the common use of the term 'shales' has been very misleading. North of St. Aubin the sedimentary series consists of dark blue-brown and grey mudstones, siltstones and coarser arenaceous bands. In age they are considered to be Pre-Cambrian, mainly on account of their similarity to the Pre-Cambrian Phyllades de St. Lô in Northern France. As yet, no recognisable organic remains have been found in this series.

In the St. Aubin area the emplacement of the granite has caused little disturbance of the regional strike (NNE.–SSW.) of the sediments. In the tunnel-cutting at St. Aubin, and in the coastal section south of the harbour, the sediments maintain a high angle of dip to the south-east or south-south-east. On both sides of the central granite lobe, to the west of St. Aubin the two narrow tongues of sediment exhibit numerous small-scale faults and folds. Locally there is a reversal of the regional dip.

North of La Rocco Tower, in the extreme north-west of the area, the sediments, which are extremely well-bedded, have a regional dip to the north-east. South of La Rocco Tower they maintain a north-westerly strike, although their dip decreases. Near to the contact, which is poorly exposed in weed-covered reefs, the sediments are hornfelsed and traversed by small granite veins, varying from one or two to twelve inches in width.

In the St. Aubin area, as well as in the north-west near to La Rocco Tower, invariably the sediments are slightly hornfelsed at their contact with the marginal granite. There is no marked aureole of thermal metamorphism in south-west Jersey. In some cases the Pre-Cambrian sediments twelve inches from the granite are only slightly indurated.

(b) **Marginal Granite.** In the north-east of the area, from Pont Marquet to St. Aubin, the marginal granite forms three distinct lobes in the Pre-Cambrian. This granite shows marked textural and mineralogical variations. The coastal section at Belcroute Bay has been chosen as the type locality to illustrate the characteristic features of the rock. The granite, in contact with, and near to the sediments, is a light brown or pale yellow rock, with abundant phenocrysts of quartz and felspar varying between 0.25 and 1.0 cm. in diameter. South of the contact there is a general increase in the size of the quartz and felspar phenocrysts. Sedimentary xenoliths, which are very abundant at the contact, decrease in size and abundance as the texture and mineralogical composition of the marginal granite approaches that of the coarser biotite-hornblende granite.

In the old railway cutting south of Pont Marquet both the marginal granite and the Pre-Cambrian sediments are exposed, the latter being mainly restricted to the north-east wall, whilst on the opposite side the marginal granite is exposed in contact with the sediments at a distance of thirty-five yards from the road. Here the indurated sediments maintain their south-easterly dip of 20°–25° right up to the granite. In colour they change from a characteristic grey-green to a light brown colour. At the contact the sediments are slightly coarser-grained than the unaltered rocks and contain abundant minute flakes of biotite. There is no evidence of basification of the sediments at this contact where the granite is extremely fine-grained, with pale pink felspars and occasional flakes of biotite rarely exceeding 0.2 cm. in length. Two feet from the contact the granite is porphyritic, with abundant quartz and felspar up to 1.0 cm. in length.

At the foot of the hill, at Mont Gras d'eau, granitic veins, varying in thickness from eight to twelve inches, traverse these diments on the eastern side of the road-cutting. These north–south veins are fairly uniform in thickness over the whole of their length.

The contact between the sediments and the marginal granite was revealed in the valley south of St. Aubin school during extensive excavations in 1948. Here the marginal granite, streaked with blue-green sediments, is also traversed by numerous small quartz veins. These seldom exceed 0.2 cm. in width and have a roughly parallel orientation. Within a hundred yards of the contact similar veins also occur, in a small quarry east of Mont Nicolle between the old railway track and the Route des Genêtes.

West of La Carrière the marginal granite, which is restricted to a few feet from the contact, is contaminated with sediments. It is streaky, tough and identical with the marginal granite of the St. Aubin area. At La Carrière, diffuse bands of altered sedimentary rock occur, which are orientated roughly east–west, i.e. parallel to the contact. Sedimentary xenoliths are uncommon in the marginal granite of this area.

(c) **Biotite-hornblende Granite.** This granite, which forms the greater part of south-west Jersey, extends from Corbière in the west to Noirmont in the east. It is well-jointed and weathers to a pale red and grey colour. Deep red staining, due to iron oxide, is common in small fissures and cracks at exposed localities.

Xenoliths which show their sedimentary origin macroscopically are uncommon, apart from the dyke-like masses described below. They are restricted mainly to the northern part of the complex, near the marginal facies. Sometimes the margins of these sedimentary xenoliths are diffuse. Frequently granite and sediment merge into each other; occasionally an abrupt division occurs between the two. In size they vary from fifteen inches to several feet in width. One large xenolith, seven feet in diameter, appears on the northern side of the rocks at La Carrière. These xenoliths are grey-green in colour, with porphyroblastic quartz and felspar. At many localities the granite contains a considerable amount of altered sedimentary rock. This occurs as diffuse bands and streaks, varying in width between 1.0 and 5.0 cm. These bands are slightly lighter in colour than the large xenoliths. Pale pink felspars, up to 1.0 cm. in length, are common in the wider bands. Most of these bands have an east–west strike.

Large dyke-like masses of altered sediments also occur in this granite. These are best exposed two hundred yards north of Point Le Fret, where they vary between a few inches and two feet in width, and between two and eight feet in length. The orientation of these blocks, which have been affected by a number of small north–south faults, is east–west. Similar dyke-like masses of altered sediments also occur in the deep gullies immediately below the large tower on the top of the cliffs at Corbière. Here the sediments are iron-rich.

In the reefs exposed at low water in the centre of Petit Port, a light coloured fine-grained rock forms a distinctive feature on the southern side of a shallow east–west gully. This rock, which is only from ten to twelve feet in width, closely resembles the marginal facies of the older granite. The northern boundary of this feature, which is over eighty yards in length, is probably a fault.

Another variation of altered Pre-Cambrian sediments is illustrated by the mass appearing in the low reefs and cliffs north of Jument (Corbière). This occurs in the older granite, and is nearly twenty yards from east to west and two to three yards across. Such rocks are much darker than the usual xenoliths; they possess irregular and diffuse margins, and are exceptionally rich in magnetite. Euhedral magnetite from 0.75 to 1.25 cm. in length is very common.

Quite distinct from the xenoliths which show some traces of their sedimentary origin are those in which no such traces can be seen. These latter are both darker and smaller than those previously described and are differentiated from the obvious sedimentary xenoliths as 'basic' xenoliths.

The average diameter of these xenoliths is 5 cm., but several exceeding 25 cm. in diameter have been recorded. They contain abundant porphyroblastic alkali felspars, occasionally rimmed with plagioclase, in a groundmass consisting predominantly of quartz, hornblende and iron ores.

Both at La Rosière, and at Portelet, the granite contains hornblende and biotite-rich bands. These bands, which are 2–4 cm. in thickness, have not been traced for more than a few feet in any exposure. The biotite and hornblende are predominantly perfect euhedral crystals, 1–2 cm. in length.

(d) **Porphyritic Granite.** Near to the microgranite the older granite undergoes both textural and mineralogical variations which are fully discussed later. It has been found necessary to distinguish the older unaltered biotite-hornblende granite from that which has been affected and altered by the emplacement of the later microgranite. In field mapping the division between the two has been taken as the limit of alteration of the older granite, and altered granite has been referred to as 'porphyritic' granite on account of this characteristic texture. This line of demarcation is purely arbitrary. Generally it is indicated by the development of a thin plagioclase rim round the perthites of the biotite-hornblende granite. At some localities a slight purplish tinge, increased resistance to weathering and erosion, and a suggestion of porphyritic texture are all indicative of the limit of alteration. The division between the porphyritic granite and the microgranite is straightforward. Often it is marked by diffuse banding due to abundant magnetite and biotite within the porphyritic granite.

At La Moye the porphyritic granite attains its maximum development. The occurrence of isolated masses of microgranite in the area suggests a western extension of the younger microgranite at comparatively shallow depths. From here to Les Creux the northern limit of the porphyritic granite is tentative. The topographic feature north-west of Bouilly Port owes its existence to two small cupolas of microgranite and the two tongues of slightly harder porphyritic granite which surround them.

From L'Ouainé to Point Le Fret porphyritic granite surrounds the eastern limit of the microgranite. The headland at L'Ouainé is formed of porphyritic granite and the cliff path follows the approximate boundary. In the reefs below, from La Cotte to Le Fret, the textures of this altered granite are extremely variably. Porphyritic granite also mantles two isolated microgranite masses lying midway between Portelet House and Point Le Fret.

In the extreme south-west of Portelet Bay porphyritic granite is characterised by an unusual development of bands, rich in biotite and magnetite, immediately above a small microgranite cupola. In this exposure, which is below high-tide mark, both the vertical and horizontal developments of these bands conform closely to the shape of the microgranite. Four clearly defined biotite-rich and magnetite-rich bands occur in this exposure, the thickness of these bands varying between five and twelve inches on the vertical face (Plate 11, A). Immediately below the lower margin of the top band is a pegmatite, three inches thick at its maximum in the centre, and two feet in horizontal extent.

A few yards to the north of this exposure are eight almost horizontal pegmatites, having a maximum horizontal extent of twenty feet. These rocks, formed predominantly of quartz crystals with their axes vertical and unorientated alkali felspar, vary between one and five inches in thickness (Plate 11, B). The total vertical distance over which these pegmatites occur is eight to ten feet, inclusive of the microgranite and the poorly-defined biotite-rich bands which occur within the pegmatites.

On the east coast, south-east of Noirmont Manor, although porphyritic granite is extensively developed there are only minor microgranite masses in this area. West of Elizabeth Castle, two miles due east of this locality, a microgranite occurs which is very similar to the La Moye and Noirmont types. It is tentatively suggested that the Noirmont microgranite may be the western end of the Elizabeth Castle microgranite. This granite has undergone marine erosion similar to that of the microgranite of south-west Jersey. Small isolated masses of porphyritic granite are also found in many other localities.

(e) **Microgranite.** Distinguished from the other granites by its texture, its reddish-brown colour and a closely-integrated joint system, this granite forms an elliptical mass in the centre of the complex. The longer axis of this mass is approximately WNW.–ESE., i.e. from La Moye to Portelet. In both of these localities the biotite-hornblende granite occurs to the south of both the microgranite and the surrounding porphyritic granite.

Marine erosion has removed almost all of the eastern half of this granite, but its original extent is indicated by granite reefs at La Cotte and cupolas in the porphyritic granite. The similarity between the form of St. Brelade's Bay and the tentative northern boundary of the eastern part of the major microgranite mass of the complex, the existence of which has been proved at Plat Houmet, suggests that in this area the extremely well-jointed younger granite has permitted marine erosion more rapidly than has the coarser and older granite. The western part, although poorly exposed inland, is perfectly exposed from Bouilly Port to Fiquet Bay. At the western end of Fiquet Bay the boundary between the microgranite and the porphyritic granite rises irregularly from sea-level to cliff-top. Down-faulted microgranite also occurs due south of this boundary, at the foot of the cliffs. From La Moye Point to Corbière many dome-like cupolas of microgranite rise into the older granite. Each such cupola is surrounded by a mantle of porphyritic granite and, as a general rule, the larger the dome of microgranite the wider zone of the alteration of the former biotite-hornblende granite to form the porphyritic mantle.

In the coastal section from L'Ouainé to Portelet frequently the microgranite rises abruptly from sea-level to form such topographical features as La Cotte seastack, and the central headland between La Cotte and Point Le Fret. This headland, which is nearly 200 ft. above the cliffs below, occurs at the eastern end of the main WNW.–ESE. axis of the microgranite of the complex. Three other minor cupolas also occur: one in the quarry on the headland; a second in the cliff-top above Portelet, where a domed instrusive roof structure is exposed, and a third at the foot of the cliff.

The very irregular surface of the microgranite and the roof structures in this area are exposed in the reefs between La Cotte and Point Le Fret at low water. There is some evidence of foliation in the older biotite-hornblende granite, presumably due to upward pressure and movement of the microgranite. At many localities pegmatitic veins occur above small microgranite masses and veins. These are on a much smaller scale than those seen at Portelet. In other localities, particularly where the rocks are exposed on the seashore, diffuse biotite-rich bands occur adjacent to microgranite veins in both the porphyritic and the unaltered older granite.

At La Rosière, La Moye, Bouilly Port and many other localities, microgranite veins cutting the biotite-hornblende granite can be traced to roots in the microgranite cupolas. In many such veins basic margins are characteristic. In other exposures the microgranite veins are irregular and occur as isolated veins in the biotite-hornblende granite in the same manner as the aplite described at the Dicq Rock in St. Helier.

(f) **Dykes.** Throughout south-west Jersey, both in the Pre-Cambrian sediments and in the granites, basic dykes and lamprophyres are common. The oldest dykes are the altered dolerites of L'Oeillère and St. Aubin; these are considered to be comparable in age with those described by Searle in south-east Jersey. The two altered dykes at L'Oeillère, eleven feet and fifteen feet in width respectively, are best exposed in the outlying reefs. Although considerably affected by a number of north–south faults, these two dykes can be traced eastwards for nearly half a mile to the cliffs at L'Oeillère. East of this point the northern dyke thins appreciably and disappears within two hundred yards. The southern dyke occurs in the cliffs and finally in La Pulente quarry, where it is barely two feet in width. Both macroscopically and microscopically these dykes are seen to be very much altered, chlorite and epidote being common alteration products. The occurrence, in the southern dyke, of an irregular granite vein 0.2 to 0.5 cm. in thickness suggests that at least this dyke may be older than the microgranite.

In the small bay south of St. Aubin are several similar dykes, having a WNW.–ESE. strike, which are almost indistinguishable from Pre-Cambrian sediments. These dykes closely resemble those described above and are tentatively regarded as being of the same age and the earliest members of the dyke swarm.

The main east–west dyke swarm, assumed to be younger than the altered and more basic dykes described above, is well exposed in the coastal section from Noirmont Manor to Portelet. The average thickness of these dykes is between two and three feet but occasionally they attain eight or ten feet in width. Nearly all of the dykes are affected by both large-scale and small-scale north–south faults. The latter, causing lateral displacements of a few inches, are very common. East of Portelet the number of east–west basic dykes exposed on the coast decreases appreciably; in several exposures thinning of the dykes occurs, both vertically and from east to west. In a few dykes the margins are brecciated, the brecciated zone rarely exceeding two inches in width.

The porphyritic dolerite dykes, which have the same east–west strike as the basic swarm, also occur in the coastal section north of Noirmont Point, and to the north of Île Percée. These porphyritic dykes are much larger than any of the dykes already described, being from fifteen feet to over twenty-two feet in width. In the area north of Île Percée several of these dykes have been faulted by two almost parallel north–south faults (Plate 12, A).

The youngest north–south dykes occur at Beau Port, Bouilly Port and in the eastern half of Portelet Bay. At Beau Port several of these dykes, from two to three feet in thickness, traverse the microgranite. One continues to the island of Grosse Tête. The relationship of these basaltic dykes to others belonging to this area is not seen at this locality. However, at Bouilly Port two north–south basaltic dykes cut dykes of the east–west swarm. The latter are displaced by north–south faults along which the later dykes have been injected. On the east side of Portelet Bay another north–south basaltic dyke, seven feet in width, traverses an earlier member of the east–west swarm; the latter shows lateral displacement but the former is unaffected by faulting.

Only two sills occur in the area: one on the western side of Portelet Bay, the other in a small coastal indentation two hundred yards east of Point Le Fret. The latter is inaccessible. The Portelet sill extends for over twenty yards from north to south, and varies between two and three feet in thickness. Macroscopically this rock resembles the dykes of St. Aubin and L'Oeillère.

Lamprophyre dykes are the youngest igneous rocks of the complex. It is not proposed to list their localities in south-west Jersey, but mention may be made of two dykes. West of Noirmont Tower, and occupying a deep north–south gully, a very fresh lamprophyre sheet, five feet in width, rises to a height of three to four feet from the gully bottom. This dyke is unusual, since most lamprophyres in Jersey have been weathered out. At

L'Oeillère, a thin north–south lamprophyre occupies the plane of the fault which has caused the lateral displacement of the oldest dykes in the area. This lamprophyre can be traced to the south for over three hundred yards.

4. PETROGRAPHY

(a) **Marginal Granite.** In Belcroute Bay, between St. Aubin and Noirmont, the marginal facies of the biotite-hornblende older granite is exposed at intervals for a distance of a hundred and forty yards. The northern part of the bay is formed of blue-grey Pre-Cambrian sediments which dip at high angles to the south-east. A predominant feature of this area is a large reef of indurated sediments which stands out from the beach deposits that cover the sediments for some distance farther south. The irregular contact between the sediments to the north, and the marginal granite to the south, is exposed only under favourable conditions of tide and beach in the reefs in the central part of the bay. Here the contact has an east–west direction; but to the west, where it is exposed in the valley near to the cottages on the private road to Noirmont Manor, its direction changes to NW.–SE.

The following variations in the colour, composition and texture of this marginal facies of the biotite-hornblende granite have been observed from its contact to a point where it is relatively free from sedimentary contamination. At the contact the granite is distinguished from the blue-grey sediments by its mottled grey-green and light brown colour, and the occurrence of small porphyritic crystals of felspar and quartz, 0.5 to 1.0 cm. in length. Within a few feet of the contact the colour and texture of the granite changes considerably. The rock now exhibits a distinctly 'patchy' appearance, with diffuse grey-green areas of hornfelsed sediment seamed with light brown granite in which large phenocrysts of quartz and felspar occur. Farther from the contact the amount of contaminating sediment decreases and the rock becomes progressively lighter in colour. Accompanying this progressive change is a general increase in the size and number of the phenocrysts of felspar and quartz. Xenoliths occur with both sharply defined and irregular margins, the latter predominating. Ferromagnesian minerals, principally biotite and iron ores, are almost absent from the marginal granite until its texture resembles that of the older granite.

Microscopically the unaltered Pre-Cambrian sediments are characterised by an abundance of angular quartz, sericitised potash and soda felspars (oligoclase Ab_{80}–Ab_{84}) magnetite, ilmenite, haematite and occasionally apatite and zircon in an extremely fine-grained groundmass consisting of quartz, chlorite, sericite and clay minerals. The larger quartz crystals contain few inclusions of chlorite and sericite. The latter mineral, which shows a slight directional arrangement and is always larger than the quartz of the groundmass, is usually associated with chlorite. This mineral, together with the accessory minerals, forms between 5% and 8% of volume of the rock.

In the hornfelsed sediments a few feet from the granite two distinct types of groundmass are present. In addition, numerous veinlets of quartz occur, many of which follow the bedding planes. The finer-grained groundmass is similar to that of the unaltered sediments; the most noticeable exception being the occurrence of glomeroplasmatic chlorite (clinochlore) and the iron ores. The coarser groundmass, which is composed almost entirely of quartz, chlorite and sericite, shows a tenfold to fifteenfold increase in grain-size when compared with that of the unaltered sediments. Quartz now exhibits serrated edges, undulose extinction and is occasionally subhedral. Magnetite, ilmenite and, less commonly, haematite (as an alteration product) are mainly confined to the peripheries of small and irregular patches of this coarser groundmass where they are often found in association with penninite, or form distinct clusters of irregular crystals. Minute felspars (oligoclase) and sporadic flakes of penninite also occur.

The coarse groundmass in the hornfelsed sediments is particularly well developed in the immediate neighbourhood of quartz veinlets, and, although many of these veinlets follow bedding planes, it is clear that the distribution of the coarser groundmass is mainly controlled by the size and pattern of these quartz veins and does not reflect differences in the original composition of the greywacke. The quartz veinlets, which vary between 0.25 mm. and 5.0 mm. in thickness, also contain muscovite, chlorite and iron ores (normally muscovite is not present in the granites). In the larger veins quartz is comparatively free from inclusions whilst in the smaller veins inclusions are very common. Further, there is often slight microbrecciation of the groundmass at the margins of some veins traversing the original bedding of the sediments. Inclusions of the groundmass in the quartz veins are, however, uncommon. In some cases small quartz crystals occur which have their '*c*' axes normal to the margins of the vein.

The contact between the hornfelsed sediments and the marginal granite is quite distinct microscopically. The granite is distinguished by porphyroblastic plagioclase (oligoclase X'/010=10°–15°, ≡12%–15% An; X'/001 =7°–9°, ≡13%–15% An)[1] perthite, quartz and microline, in this order of relative abundance. These porphyroblasts vary from 0.2 to 0.5 cm. in length; frequently they contain numerous flakes of sericite, angular clastic quartz, chlorite and iron ores of the same textural pattern as the groundmass of the sediments. At the contact the groundmass of the granite closely resembles the coarse-grained groundmass developed in the neighbourhood of the quartz veinlets in hornfelsed sediments.

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[1] In this, and subsequent felspar determinations, the first values given represent the averages of a number of readings of the maximum extinction angles measured in the symmetrical zone in either one, or several, slides. The second series include values obtained using the Fedorow stage.

Within a few feet of the contact plagioclase felspar porphyroblasts become subordinate in frequency and size to those of both quartz and perthite. Micro-faulting, brecciation and mechanical deformation of all minerals are extremely common. Plagioclase is much more affected than the alkali felspars and is considered to be of earlier growth. In the early stages of growth of xenoblastic quartz the random optical orientation of clastic quartz grains derived from the sediments are unaffected by subsequent growth. In later stages, several feet from the contact, where individual clastic relics in a composite xenoblastic quartz cannot be recognised, the mineral exhibits apparent undulose extinction between crossed nicols.

Several yards from the contact there is a general increase in the size of all the constituent minerals and a rapid diminution in the amount of derived and contaminating sediment to less than 5% by volume. Here quartz shows a new textural feature; frequently adjacent quartz xenoblasts are optically continuous. Near to the normal biotite-hornblende granite, optically-continuous and embayed relics of quartz are common, both in the main fabric of the rock and in perthites. Ferromagnesian minerals, noticeably absent in the contaminated marginal granite near to the contact, first appear as small clusters of biotite, penninite, the iron ores, apatite and occasionally zircon, as the texture approaches that of the uncontaminated granite.

Large sedimentary xenoliths, often showing diffuse margins, exhibit over a few inches the same general sequence of textural and mineralogical

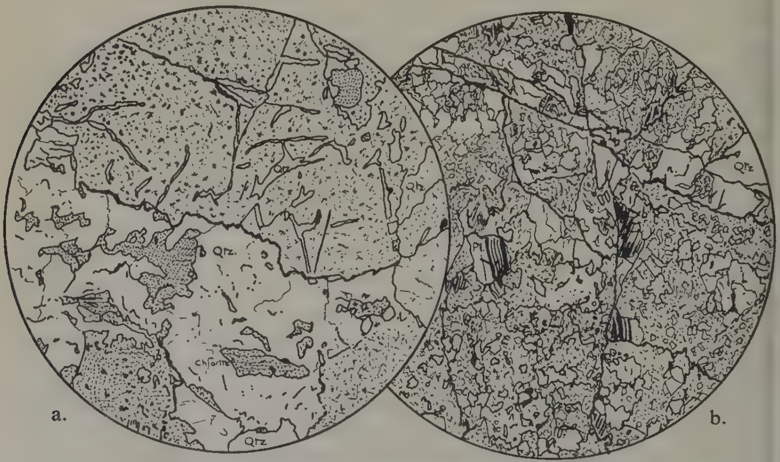


Fig. 2. (a) Quartz vein, with chlorite, traversing indurated Pre-Cambrian sediments, Belcroute Bay. (× 10). (b) Marginal granite, Belcroute Bay. Brecciated contaminated marginal granite containing abundant quartz, perthite and oligoclase. Specimen from two feet from the contact. (× 12)

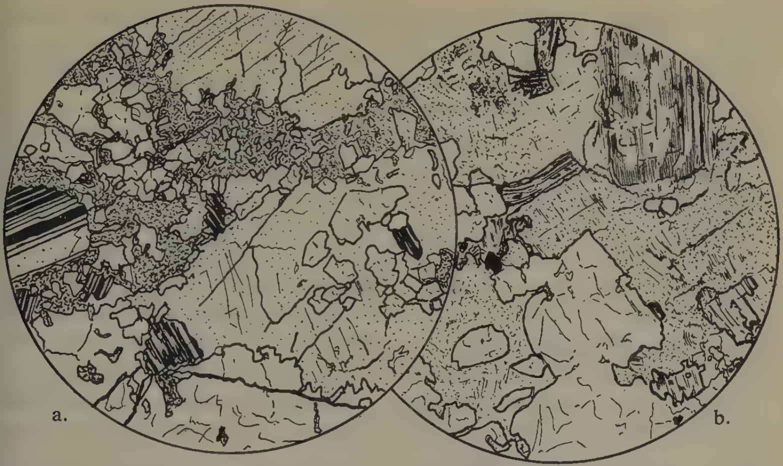


Fig. 3. (a) Marginal granite, Belcroute Bay. Porphyroblastic felspars and quartz in granite at twenty feet from the contact. Perthite (stippled) contains optically-continuous quartz relics. (× 10). (b) Marginal granite, Belcroute Bay, 240 ft. from the contact. (× 10)

changes as are seen over many yards in the marginal granite. It is emphasised that the general changes described above are frequently repeated within the exposures of the marginal granite at Belcroute Bay. Marginal granites from many other localities in the St. Aubin area exhibit this general trend of alteration, of brecciation and of textures.

(b) **Biotite-hornblende Granite.**

(i) *Normal type*. Macroscopically, this granite is a mottled pale pink and grey rock (when fresh) of medium to coarse grain, consisting of abundant quartz, pale felspars (up to 2.5 cm. in length) with shining plates and aggregates of biotite disseminated throughout. Hornblende, up to 1.0 cm. in length, is sporadic in its distribution and usually is found in association with biotite and the iron ores. When weathered, the granite is a darker pink and grey, due to the alteration of the potash felspars.

Microscopically, the texture is hypidiomorphic and unorientated. Fluorspar, apatite, zircon, allanite, sphene, epidote, clinozoisite and iron ores are also present. Quartz frequently exhibits slight undulose extinction and embayed margins. Inclusions of perthite, microcline, sericite, penninite and zircon are common. Quartz is also present in perthite, where it occurs as corroded and embayed relics in optical continuity with each other. Similar relics in plagioclase are both smaller and less common. Perthite is abundant, and two varieties are present. In one the albite lamellae are clearly defined and have a common orientation in their orthoclase host. Perthite is normally present as the braided type, however, appearing in subhedral and anhedral forms, and inclusions are common. In addition to quartz relics in optical continuity (as described above) this mineral also occurs in a few perthites as minute optically un-orientated grains exhibiting sub-parallel arrangements. 'Ghost' structures of earlier perthites also occur where cleavage directions are different from those of the later mineral. Sub-parallel arrangements of quartz grains are confined to these earlier perthites mainly. Plagioclase (oligoclase X'/010=10°–11°, ≡An. 14%–16%; X'/001=5°–6°, ≡An. 15%) occurs as inclusions in perthite, as well as biotite, penninite and other accessory minerals. Micrographic intergrowth of perthite and quartz is common.

Plagioclase, both euhedral and subhedral, exhibits zoned structures; many relics of optically-continuous quartz, and more rarely biotite, perthite and penninite inclusions are found at the centres of the crystals. The margins of the larger zoned plagioclases are more acid than their centres (X'/010=10°–13°, centres 8°–10° corresponding to oligoclase An. 16%–12% and An. 20%–16% respectively).

Biotite occurs throughout in the form of aggregates or clots of flakes. The associated minerals are fluorspar, allanite, hornblende and other accessories. Biotite is strongly pleochroic ($X<Y$), with X straw yellow, Y dark brown. The flakes are unorientated, occasionally deformed, and exhibit pleochroic haloes. Inclusions are very common and alteration to chlorite, epidote and less commonly to magnetite and haematite, has taken place. Nearly always hornblende is associated with biotite and the accessory minerals. Some large hornblende crystals, containing numerous flakes of orientated biotite, appear to have grown at the expense of biotite. This reversal of the usual reaction series may indicate a local basification phase associated with relic xenolith structures. Very rarely, hornblende (with biotite inclusions) occurs in plagioclase.

Crushed granite is restricted to very narrow fault zones. This granite, which is grey in the field, shows very strained and fractured quartz under the microscope as well as sericite and muscovite (1%–4%). Large patches of sericite and quartz, seen at high magnification, show a roughly parallel orientation; they appear to be the direct result of alteration of the original felspars present. No accessory minerals have been distinguished in these rocks; sometimes penninite is present.

(ii) *Banded Sedimentary Xenoliths.* Macroscopically, these xenoliths vary in size, in the relative abundance of microgranitic veins within them and in the degree to which metasomatic changes have taken place. Often the margins of these banded xenoliths are diffuse, whilst in their immediate neighbourhoods the granite is contaminated by irregular and contorted streaks of sedimentary material derived from the xenoliths. Probably this indicates that mechanical deformation, as well as metasomatic changes, have occurred.

Microscopically, the fine-grained bands are similar to the indurated sediments; both angular and serrated 'clastic' quartz are common. Oligoclase (X'/010=14°–15°, ≡An. 10%; X'/001=10°–11°, ≡An. 9%–10%) is more abundant than perthite. Porphyroblastic quartz crystals often exhibit serrated edges; they are composite in appearance, and contain numerous inclusions identical with those of the groundmass. Frequently oligoclase is bent and fractured. The coarser bands are characterised by a marked increase in grain-size in all constituents. Quartz grains up to 1.0 cm. are common, whilst biotite, the iron ores, apatite and zircon also occur. Cordierite is present only very occasionally, usually associated with quartz and oligoclase.

(iii) *Granite Streaked with Sediments.* This marks the final stage in the assimilation of the sedimentary rocks. The streaks rarely exceed 5 cm. in width and in thin section show 'clastic' quartz with subordinate biotite and chlorite. Porphyroblastic quartz, oligoclase and perthite are abundant. The textures developed are similar to those already described in the Belcroute traverse (p. 276).

A new feature at this stage is increase in the amount of quartz not only in the forms described above, but as perfect euhedral crystals adjacent to large composite crystals. Such crystals show growth stages in the form of zoned inclusions. Euhedral quartz crystals, unlike the composite quartz porphyroblasts, give normal extinction. A second feature is that quartz rims perthite (in contrast to the earlier stage where optically-continuous quartz relics occur in perthite). These earlier relics are rarely preserved in perthite which is rimmed with quartz. Also there is parallel orientation of chlorite and sericite and euhedral zircons in quartz.

(iv) *Le Fret Xenoliths.* Blocks of altered Pre-Cambrian sediments, elongate east–west, occur in the reefs one hundred and fifty yards north-east of Point Le Fret. The western block, twelve feet long and five feet in width, is the longest. Other blocks in the area exhibit the same orientation, although displaced laterally by numerous minor north–south faults.

Macroscopically, this series shows gradation from partial alteration to almost complete alteration of the original sediments. The central parts of the blocks are dark coloured and compact, but their margins are light brown. Primary banding is preserved and the textures are identical with those described above. Porphyroblastic quartz and felspars are common at the margins.

Microscopically, the first change (preserved in the central zone of the xenoliths) has been the growth of composite quartz in the groundmass. The direction of growth was influenced by bedding. Undulose extinction is again common and it is suggested that the undulose extinction in such grains is not a reflection of tectonic history, but of their origin. In many xenoliths, rows of clastic quartz grains indicate original bedding. Haematite, penninite and associated minerals occur as inclusions. Felspar is subordinate in amount at this stage; oligoclase is more abundant than perthite. Subsequent stages of alteration show the same textural and porphyroblastic sequence as have been described above.

(v) *Jument Xenoliths*. Megascopically, these rocks are much darker than the normal sedimentary xenoliths, owing to the abundance of magnetite. This mineral is scattered throughout but is most abundant at the centres of these dyke-like masses and decreases towards their margins. There is a complementary increase in the amount of felspar and quartz present.

Microscopically, in addition to the usual suite of minerals present in sedimentary xenoliths, magnetite is very abundant in the central parts of the Jument xenoliths. This mineral occurs both in, and at the margins of porphyroblastic oligoclase (X'/010=12°–14°, ≡An. 12%–14%; X'/001 =8°–9°, ≡An. 13%–14%), microcline and orthoclase. Oligoclase exhibits parallel micro-displacement of the lamellae in all sections examined. Perthite is absent from the central parts of these xenoliths. Magnetite is less common in xenoblastic quartz than oligoclase, microcline and orthoclase. Nearer to the margin perthite has developed, and although the amount of oligoclase exceeds that of perthite, the crystals are all brecciated. Euhedral magnetite, still plentiful, now commonly occurs in the interstices. At the margins perthite increases, both in amount and size, whilst oligoclase and quartz decrease and increase respectively. Hornblende has not been identified, but chlorite pseudomorphs exhibiting its characteristic cleavages suggest that it was once present. Apatite, sphene and epidote also occur. There is no reason to doubt that originally this mass was a large block of Pre-Cambrian sediment of similar composition to the sediments which occur to the north of the granite mass. It is possible this is a roof fragment, but whatever its structural relationship to the granite it is clear, both in the field and in thin section, that this rock has undergone considerable alteration, the first phase of which was enrichment in iron.

(vi) *Summary of Changes Exhibited by Xenoliths*. Sedimentary xenoliths in the granite show a well-defined sequence of alteration and these are independent of the sizes of the original blocks of sediment. Mechanical deformation and progressive mineralogical changes, partly assisted by original bedding, are thought to be responsible for the banded xenoliths. Further movement, accompanied by mineral changes generally following the order given below, resulted in the 'streaking out' of the xenoliths and eventually the formation of fine sedimentary streaks and bands in granite. In large blocks of sediment mechanical deformation played a subordinate part, although a roughly parallel east–west orientation of the blocks themselves occurs. The main changes are zoned mineral assemblages and textures, identical with those observed in the Marginal Granite.

In the Jument series the changes resulted in an iron-rich rock at first, with the growth of euhedral magnetite throughout. This initial change was followed by an increase in the amount of biotite and chlorite present, together with an increase in grain-size. Porphyroblastic quartz, oligoclase (showing micro-faulting and brecciation) and perthite occur in this order of formation. Finally, quartz becomes very abundant and rims earlier perthite as well as forming euhedral crystals.

(vii) '*Basic*' *Xenoliths*. The basic xenoliths consist essentially of granular hornblende, biotite, oligoclase and a small amount of quartz and accessory minerals at the margins of the xenoliths. Zoning is quite distinct in small xenoliths up to 5 cm. in diameter. Their centres are composed of hornblende and biotite, with subordinate quartz. Towards the margins there is a progressive increase in the size and amount of porphyroblastic oligoclase (X'/010=12°–13°, ≡An. 13%–15%; X'/001=7°–9°, ≡An. 12%–15%). Perthite is sporadic in its distribution, it is usually absent in such small xenoliths.

In the larger xenoliths are irregular basic patches, similar to those described above. Surrounding them is a fine-grained mass of oligoclase, quartz, biotite, microcline, hornblende and perthite. Some of the oligoclase occurs as porphyroblastic laths extending into the basic cores. Such felspars usually contain relics of biotite and hornblende, identical with those in the basic cores. Furthermore, many of the felspars, even in these dark 'basic' xenoliths, contain relic quartz similar to the clastic grains in the marginal granite. In many of the larger xenoliths abundant porphyroblastic alkali felspars also occur. Often these are rimmed with oligoclase, which shows a deep yellow colour on weathered surfaces in contrast with the deeper red of the perthites. Occasionally larger porphyroblastic crystals of quartz occur at the margins of these xenoliths.

At La Rosière diffuse bands of unorientated biotite and hornblende, 2–4 cm. in width and forming 30% to 40% of the volume of the rock, have been found in the granite. The biotite contains abundant inclusions of zircon, apatite, ilmenite, quartz and sericite. Biotite also occurs as corroded relics in hornblende, where, clearly, it is subordinate. The latter occurs as subhedral and perfect euhedral crystals, up to 0.75 cm. in length, which are strongly pleochroic (X=Pale Green, Y=Olive Green and Z=Bottle Green with $X<Y<Z$, Biaxial –ve with X'/010=18°–22°). Many of the corroded biotite flakes are in optical continuity with enveloping hornblende. This, together with the occurrence of sphene, zoisite, allanite and epidote, indicates a local phase of basification.

(c) **Porphyritic Granite.** In texture, composition, and size and abundance of the phenocrysts, this granite is extremely variable. At its outer limit it closely resembles the unaltered biotite-hornblende granite whilst at its contact with the microgranite it is distinguished from this rock only by the occurrence of porphyritic quartz and felspar. At many localities, within a few feet or inches of the microgranite, this porphyritic granite shows well-marked banded structures. Such bands seldom exceed six inches in thickness.

Micrometric analyses of unorientated specimens of porphyritic granite which had been collected along two traverses from the biotite-hornblende granite to the microgranite (at Bouilly Port and at La Cotte) indicated several variations in the mineralogy and texture of the porphyritic granite. Both ferromagnesian minerals and plagioclase felspar progressively decrease in amount near to the microgranite whilst there is a complementary increase in the amount of perthite and quartz close to the microgranite. On both traverses, within a few inches of the microgranite, there is a distinct banding due to abundant biotite and iron ores. Texturally the variations along the Bouilly Port traverse are the more interesting of the two. First there is a general decrease in the grain sizes of quartz, perthite and plagioclase on passing from the biotite-hornblende granite to the microgranite. The largest phenocrysts of both quartz and perthite occur at the centre of the traverse, whilst the largest plagioclase phenocrysts occur much nearer to the microgranite.

Another point of interest shown in Fig. 4, and of particular interest along the Bouilly Port traverse, is that there is a suggestion of cyclic mineralogical variation along this line evidenced by the occurrence of darker zones extending laterally for over twenty yards or more.

Banded porphyritic granite also occurs above a small microgranite dome in the extreme south-west of Portelet Bay where the porphyritic granite in the immediate neighbourhood of the microgranite is characterised by several bands rich in biotite and iron ores. Four such bands are exposed in an east–west vertical surface immediately above the microgranite (Plate 11, A). The uppermost and darkest of these bands is over twelve inches in thickness, and its position varies from two to over four feet above the upper surface of the microgranite. Three other bands, varying from four to nine inches in thickness, also occur. Between these biotite-rich bands the granite is markedly porphyritic, with quartz and felspar phenocrysts up to 1.0 cm. in length. Above the thickest band the perthites are rimmed with plagioclase. Both above and below the highest part of the uppermost band are small pegmatitic veins two feet in horizontal development and three inches at their maximum vertical extent.

These four biotite-rich bands have been traced horizontally for several yards in this exposure and have been found to form a series of roughly concentric bands about the microgranite dome. Their maximum development has taken place above the approximate centre of the microgranite mass; here the vertical development of the bands is twenty inches, compared with a few inches ten feet to the east or west. Furthermore, it is at this point that the pegmatitic veins occur. These bands are therefore

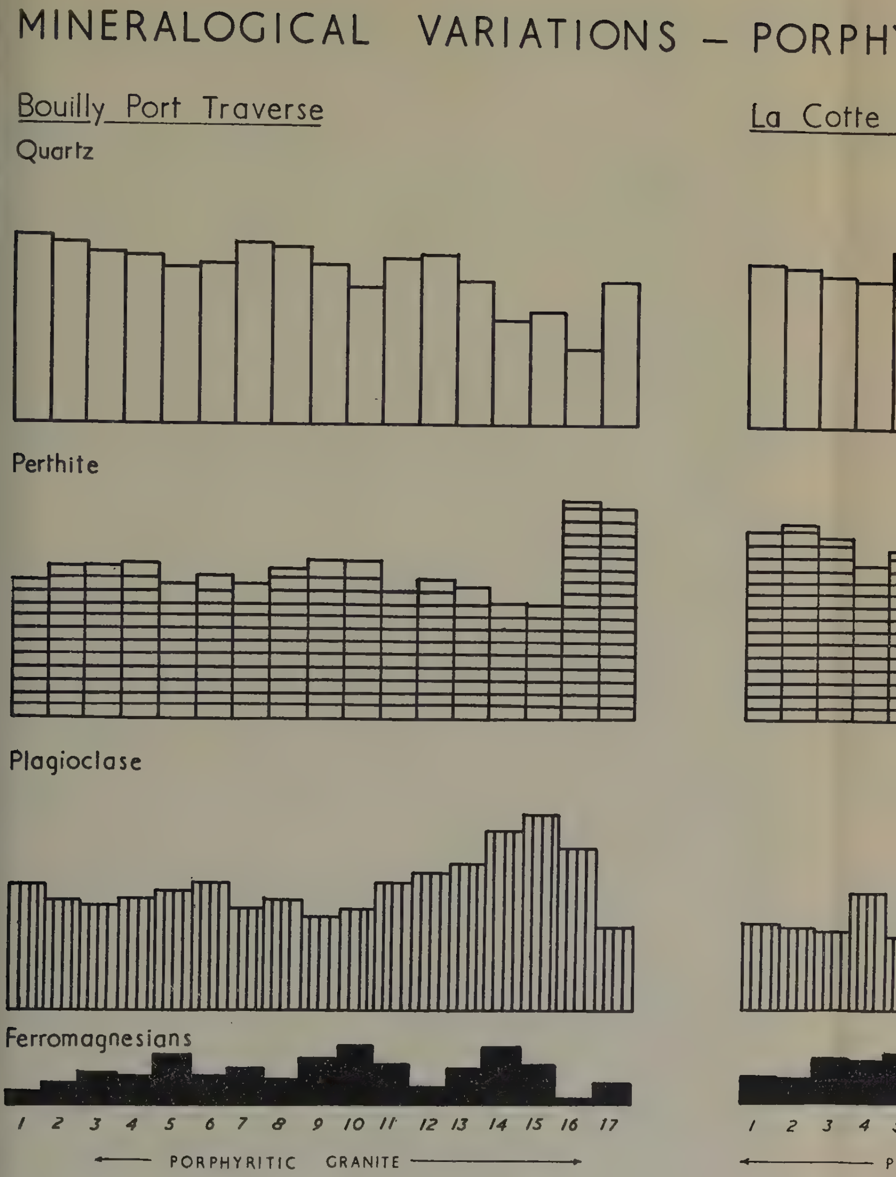

MINERALOGICAL VARIATIONS – PORPH
Bouilly Port Traverse
La Cotte
Quartz
Perthite
Plagioclase
Ferromagnesians
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
← PORPHYRITIC GRANITE →
1 2 3 4
←

Fig. 4

interpreted as local diffusion phenomena directly attributable to the emplacement of the microgranite at this locality. There is no possibility that these bands are relics of sedimentary xenoliths or structures present within the porphyritic granite prior to the emplacement of the younger granite.

Microscopically, biotite forms 20%–25% of the banded porphyritic granite and occurs mainly as thin interstitial flakes 0.2 to 0.5 cm. in length. Haematite, ilmenite, chlorite, apatite, hornblende (relics) and sphene also occur. The texture of the rock resembles that of the porphyritic granite near to the microgranite in the Bouilly Port traverse. The upper bands show the coarsest texture.

Fifteen yards north-east of this exposure similar, though poorly-defined dark bands occur in association with a series of horizontal pegmatite veins. The pegmatites, which vary between three and six inches in thickness, form two distinct groups separated by three feet of microgranite. The lower group, consisting of four pegmatites interspersed with microgranite, occupies three feet vertically. The upper group, which is irregular in horizontal extent, comprises three pegmatite veins. The dark biotite-rich bands are restricted to the porphyritic granite immediately above the upper group, and to the microgranite between the two groups. In many other localities the junction between the porphyritic granite and the microgranite is marked by the development of a single pegmatite.

(d) **Microgranite.** The microgranite is distinguished from the other granites by its texture and deep red colour on weathered surfaces. Microscopically this granite shows no evidence of relic textures derived from either of the other granites. The microgranite is almost uniformly fine-grained and equigranular in texture. The average grain-size of quartz and felspar is 1.0 mm. There are some variations, particularly in the aplitic veins and in the central area where the granite is slightly coarser. The constituent minerals are quartz, perthite, plagioclase (Oligoclase X'/010 =11°–14°, ≡An. 12%–16%; X'/001=6°–9°, ≡An. 13%–16%) and ferromagnesian minerals, which include biotite, iron ores and hornblende. The latter is present only sparingly.

Quartz appears in the form of small irregular grains, the edges of most of which are serrated. Fractured grains are quite common. It contains few inclusions, apart from occasional flakes of sericite, and isolated fragments of plagioclase and biotite. In many cases adjacent grains of quartz are optically continuous and suggest replacement phenomena. Less frequently a large number of grains extinguish simultaneously, again indicating replacement. Perthite is very common, abundant crystals showing Carlsbad twinning and inclusions of plagioclase, while quartz and flakes of biotite and sericite are frequent. The perthite tends to be anhedral. It is identical with the braided variety found in the earlier granites. Plagioclase, both as inclusions within perthite, and as subhedral crystals showing good twinning, is common. The composition is slightly more acid than in the biotite-hornblende granite. Biotite, considerably altered to chlorite, is present only very occasionally in any amount (2%–5%). Frequently it contains inclusions of apatite, magnetite, zircon and fluorspar. The other minerals present in this rock are epidote, hornblende, haematite and allanite, the last being extremely rare.

5. CHEMICAL ANALYSES

The chemical analyses given below are considered to be representative of the variations in the granites and sedimentary rocks of south-west Jersey. They are not intended to reflect all transitional phases between the granites.

The Pre-Cambrian sediments, represented by (1) a fresh specimen (from St. Aubin) typical of the series both macroscopically and microscopically, are rich in SiO_2 and MgO. All percentages of MgO, TiO_2 and P_2O_5 in this rock are higher than those found in either the granites or the xenoliths. The marginal facies of the biotite-hornblende granite (2) comes from within twelve inches of the contact; and when compared with (1) shows an increase in SiO_2, K_2O and Na_2O, whilst FeO, Fe_2O_3, TiO_2, CaO and P_2O_5 have decreased in amount. Comparing this analysis (2) with that of the biotite-hornblende granite, it is seen that the marginal facies is richer in SiO_2, Fe_2O_3 and K_2O and poorer in Al_2O_3, FeO, TiO_2, MnO, CaO, MgO and Na_2O than the older granite. The absence of P_2O_5 in the marginal granite is reflected, microscopically, by the absence of apatite from the marginal granite near to its contact with the Pre-Cambrian rocks.

In the analyses of the three main granites, i.e. the biotite-hornblende granite, the porphyritic granite and microgranite, there is a progressive increase in the amount of SiO_2 present, while Al_2O_3, TiO_2, MnO, CaO and MgO show a complementary decrease. The sequence is one of increasing silica-content, but the intermediate porphyritic granite is richer in K_2O, and contains less Na_2O, then the other granites. A more striking variation of the porphyritic granite would be shown in specimens 15–17 of the Bouilly Port traverse.

Obviously the source and original composition of the sedimentary xenolith represented by analysis (6) are unknown, but since this xenolith came from within the marginal granite, at thirty yards from the contact in Belcroute Bay, it may be used to indicate possible changes which the Pre-Cambrian sediments have experienced. Clearly there is little difference in the amounts of SiO_2 in analyses (1) and (6); while the xenolith is only richer in Al_2O_3 and Na_2O relative to the sediments from St. Aubin. It is significant that the amount of Na_2O present exceeds that in any of the other analyses. Moreover, since Na_2O is very much in excess of K_2O (the value of 0.51 of analysis 6 is the lowest for the series), this confirms microscopic evidence that in the altered sediments sodic felspars are nearly always of earlier growth than potash felspars.

Chemical Analyses

	1	2	3	4	5	6	7	8	9	10
SiO_2	66.39	77.03	69.29	73.46	73.95	65.82	70.38	72.04	43.56	70.23
Al_2O_3	15.96	12.92	16.06	13.96	13.28	18.49	14.80	14.04	14.58	14.73 (+TiO_2)
FeO	4.72	1.05	3.76	1.92	2.41	2.86	3.03	Nil	7.00	0.98
Fe_2O_3	0.05	0.19	0.03	0.78	Tr.	1.44	0.08	3.13	3.84	2.37
TiO_2	0.58	0.08	0.32	0.26	0.16	0.28	0.39	Nil	1.03	Nil
MnO	0.18	Tr.	0.06	0.04	Tr.	0.03	0.06	Nil	0.39	0.18
CaO	0.86	0.47	1.34	0.94	0.83	0.30	1.52	1.61	10.78	0.94
MgO	2.18	0.16	0.48	0.28	0.15	0.66	0.38	0.43	9.95	0.50
K_2O	2.97	4.27	3.42	4.29	4.26	0.51	4.46	4.13	1.02	5.13
Na_2O	3.05	3.12	4.46	3.36	4.37	7.78	3.73	3.86	1.86	4.19
H_2O–105°C.	0.22	0.05	0.17	Nil	Nil	0.14	0.27	0.44	3.85	0.70
H_2O+105°C.	2.03	0.70	0.33	0.89	0.50	1.46	0.73			
CO_2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	1.93	
P_2O_5	0.23	Nil	0.07	0.07	Tr.	0.07	0.04	Nil	Nil	Nil
	99.42	100.04	99.79	100.25	99.91	99.84	99.87	99.68	99.79	99.95

1. Pre-Cambrian, from old railway tunnel, St. Aubin.
2. Marginal granite, Belcroute Bay, St. Aubin.
3. Biotite-hornblende granite, Noirmont Tower.
4. Porphyritic granite, La Cotte Point.
5. Micrograinite, La Moye Semaphore Station.
6. Sedimentary xenolith, Belcroute Bay.
7. Basic xenolith, Corbière.
8. Granite, St. John's.
9. Dolerite, Fort Regent.
10. Granite, Fort Regent.

Chemical Analyses 1–7, W. H. Herdsman, Analyst.
Chemical Analysis 8, J. F. G. Boerlage, Analyst.
Chemical Analyses 9 and 10, P. Holland and E. Dickson, Analysts.

Norms

	1	2	3	4	5	6	7
Quartz	29.58	40.81	24.33	34.02	28.78	15.48	27.00
Orthoclase	17.57	25.24	20.24	25.36	25.15	3.02	26.38
Albite	25.41	26.36	37.72	28.40	39.24	65.73	29.40
Anorthite	3.19	2.34	5.1	4.17	4.12	1.08	7.36
Corundum	6.63	2.22	2.73	2.21	0.15	3.70	1.50
Hypersthene	13.06	1.45	7.67	3.5	3.61	5.30	5.85
Magnetite	0.73	1.29	0.44	1.14	Nil	2.08	0.16
Ilmenite	1.1	0.15	0.61	0.47	0.30	0.53	0.76
Apatite	0.55	Nil	0.54	0.16	Nil	0.17	0.09

Analysis (7) is of a 'basic' xenolith. It comes from porphyritic granite, near to the biotite-hornblende granite. Macroscopically this rock is comparatively dark. It contains more SiO_2 than the older granite; the percentages of FeO, TiO_2, CaO, MgO, and Na_2O are high. It seems most unlikely that this is an altered basic rock such as gabbro. Further, in south-west Jersey there was no basic roof to the granite, as in the case of the basic sheet covering the Ronez complex, or the Tregastel–Ploumanac'h granite. Compared with the analysis of the biotite-hornblende granite (3), this analysis of the 'basic' xenolith shows interesting features. Both contain nearly equal amounts of SiO_2, Al_2O_3, TiO_2 and MnO, while Fe_2O_3, CaO and K_2O are more abundant in the xenolith.

Analyses (8) and (10) are of the granites from St. John's and Fort Regent respectively. They closely resemble the porphyritic and biotite-hornblende granites. The amount of Fe_2O_3 in the former is unusual and presumably contains FeO, whilst the amount of Fe_2O_3 in the latter is the highest in the series. Certainly the analysis of the Fort Regent granite does not closely resemble that of the microgranite from La Moye; the value of 5.13 for K_2O seems suspect. However, these analyses of rocks derived from outside the area under consideration show certain chemical affinities which may indicate that the granites of St. John's and Fort Regent are genetically related to those of south-west Jersey.

6. CONCLUSIONS

In the preceding pages the field relations and petrography of the granites and associated rocks of south-west Jersey have been described. In this area the relationship between topography and structure is brought out by inland drainage features and coastal features. Important in this last respect is the similarity between the shoreline of St. Brelade's Bay and the northern boundary of the microgranite. East of the area described, another microgranite mass probably exists between Noirmont and Elizabeth Castle, but, like the granite at St. Brelade's, it has been mainly eroded away.

At St. Aubin the marginal granite is clearly a roof structure, in which the degree of contamination is controlled by the surface area of the granite lobes or tongues. This contrasts with the wall features of La Carrière. In the La Cotte region, at the eastern end of the elliptical mass of the microgranite, the younger granite also shows roof structures while in the La Moye area, although cupolas are revealed in the coastal section, the main walls of the microgranite mass plunge steeply. This suggests that the whole of the complex is tilted slightly to the east. The elliptical form of the younger granite mass, with the longer axis WNW.–ESE., corresponding to the trend of Dinantian axes in Normandy, strongly suggests that this granite, and indeed the earlier granites, are of Carboniferous age.

The Pre-Cambrian sediments in the St. Aubin area do not show evidence of either extensive metamorphism or of basification in the immediate neighbourhood of the marginal granite. The contacts between sediments and granite are clearly defined in the St. Aubin area; furthermore, the sediments have been pushed aside by tongues of contaminated marginal granite. This rock, in the Belcroute section, is distinctly zoned and contains abundant porphyroblastic felspars and quartz. Also it shows considerable brecciation. The textures and mineral assemblages described in this granite are taken to be indicative of the mechanism by which the granite has assimilated the sediments. Predominantly, this process is one of mechanical deformation, accompanied by the injection of quartz veins and local recrystallisation, followed by felspathisation (in which sodic felspars are the first formed) and subsequent silification. The mechanism of emplacement is not considered to be one of granitisation.

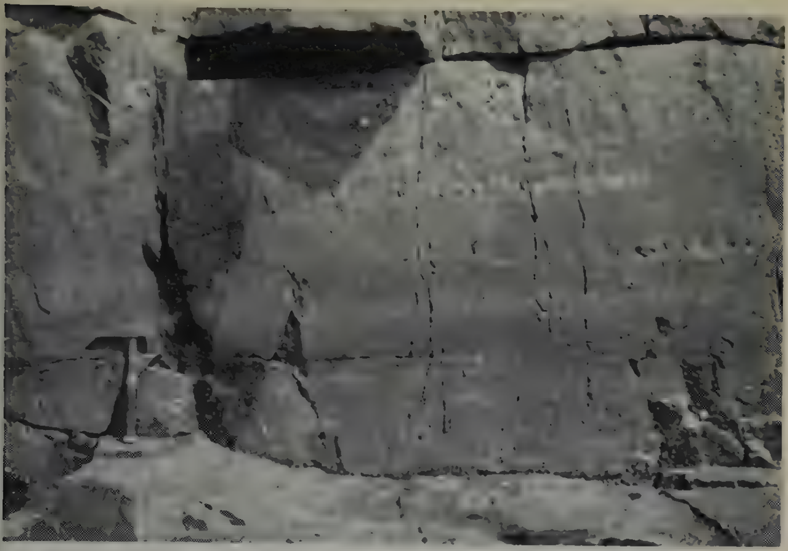
The sedimentary xenoliths in the biotite-hornblende granite also show the same stages of mechanical deformation and felspathisation as is outlined above. The Jument xenoliths, however, do indicate some basification of the original sediments, which are now rich in magnetite, hornblende, biotite and allanite. The east–west orientation of many of the xenoliths—particularly the larger blocks—parallel to Dinantian axes also suggests a Carboniferous age for the granites.

The variations in texture and composition of the porphyritic granite, as revealed by the Bouilly Port and La Cotte traverses, suggests that the older biotite-hornblende granite was probably a viscous crystal mush when the microgranite was emplaced. Under such conditions, the repeated metasomatic diffusion and replacement effects already described were able to change the character of the earlier granite up to distances of a hundred and forty yards from the microgranite. In the case of a small microgranite dome, as at Portelet, the limit of these metasomatic changes is restricted to a few feet. Here the concentric arrangement of biotite-rich and magnetite-rich bands around the microgranite dome can only be interpreted as diffusion phenomena. Where aplitic veins traverse either the porphyritic granite, or the biotite-hornblende granite, similar diffusion effects are frequently observed. These effects are limited, however, to a few inches. From these observations, both in the field and in the laboratory, it seems reasonable to assume that the extent of alteration of the older granite, with the production of the porphyritic variety, was largely controlled by the amount of energy available. This seems to be dependent on the size of the microgranite vein, dome or major mass of the complex. Since the porphyritic granite, like the older granite, is traversed by numerous aplitic veins (identical with the microgranite), it would appear that metasomatism accompanied emplacement, and does not represent the final dissipation of energy into the older rock. This does not necessarily imply the absence of magma, since many of the microgranite cupolas and apophyses occur as perfect domed and intrusive structures. In the time required for the intrusion of the microgranite, both in the major elliptical mass and the apophyses, some of the constituents of the magma migrated through the older granite. These resulted in the cyclic metasomatic changes. Clearly this is not a case of solid diffusion, since the distances involved are many times those found experimentally. These metasomatic effects are considered to have taken place under favourable temperature and pressure conditions, and to have been greatly assisted by the partially consolidated nature of the older granite. Replacement effects, like those described in the Bouilly Port traverse, are incidental and are not responsible for alteration of the older granite.

These granites, like those of Cornwall and Devon, are considered to be high-level and younger members of the Hercynian granite series. They are apotectonic. The absence of gneissose rocks in Jersey (although they occur in Guernsey and in some of the larger reefs in the Channel Islands) and the very slight hornfelsing of the Pre-Cambrian, support this view. Read has described the granites of south-west England as being ‘almost dead when they arrived in their present positions’. Certainly the granites of south-west Jersey were approaching this condition when they were emplaced.

With the development of tensional stresses the intrusion of the dolerite dykes occurred, generally following east–west directions. North–south basaltic dykes and lamprophyres mark the final stage in the igneous history.

The following sequence of igneous activity for the area is proposed:



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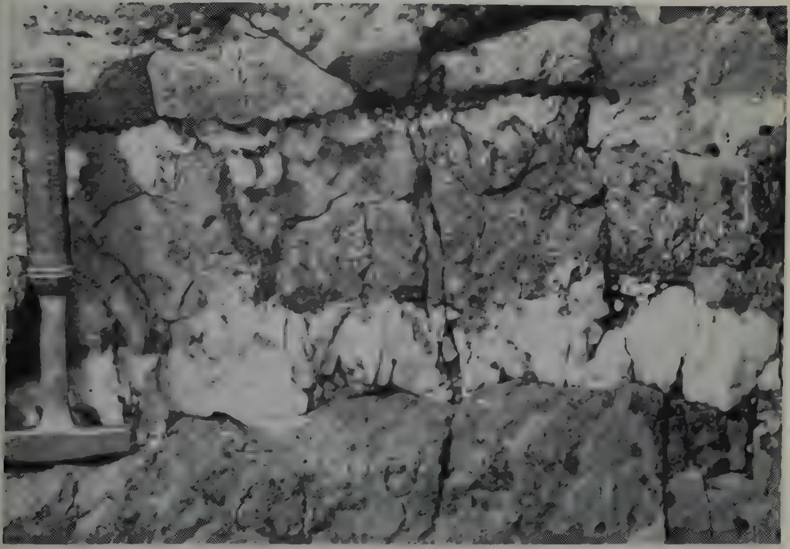

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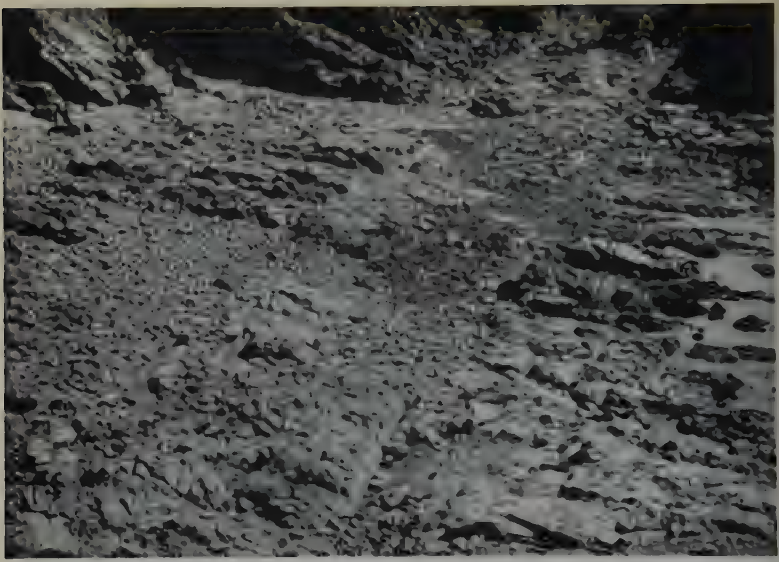

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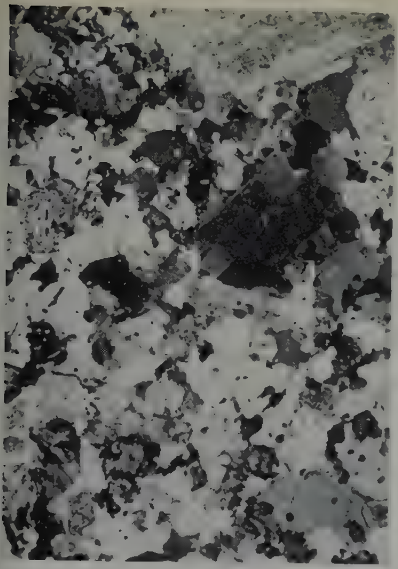

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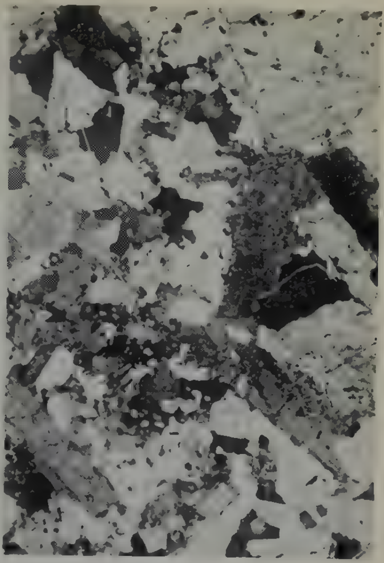

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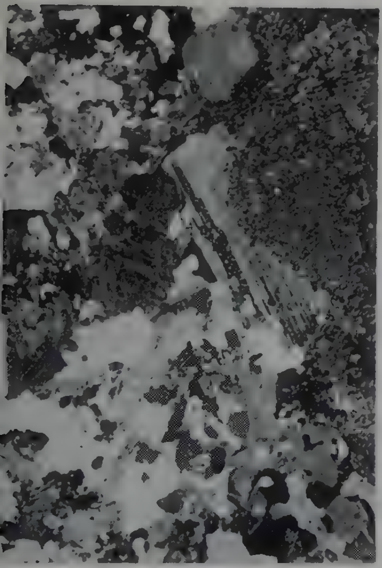

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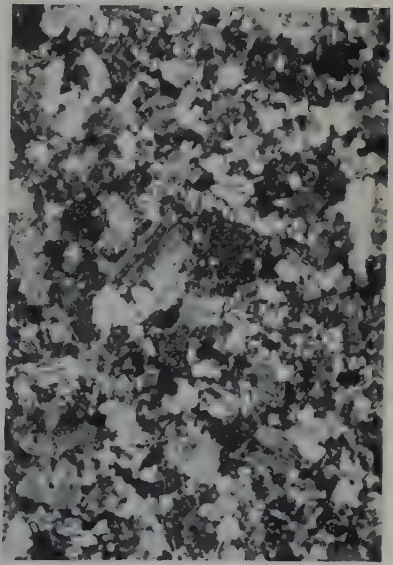

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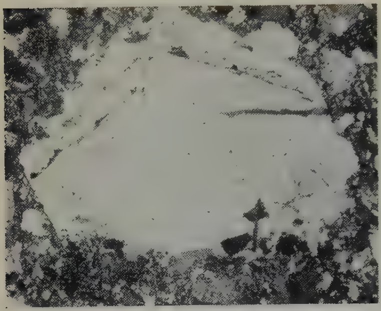

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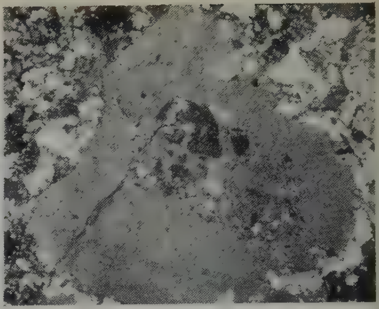

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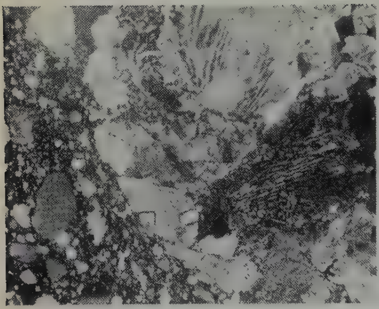

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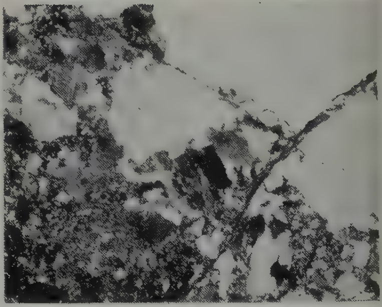

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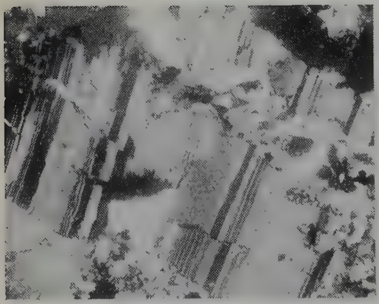

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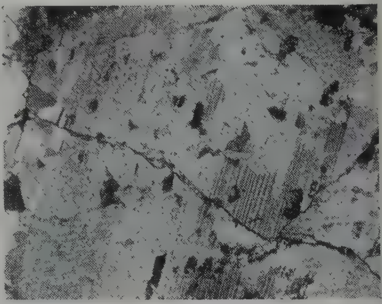

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Mica lamprophyres		PERMIAN
North–south basaltic dykes		
East–west dyke swarm	c. Fine-grained dolerites b. Porphyritic dolerites a. Older dykes of L'Oeillère and St. Aubin	
Microgranite		Age uncertain: Probably late CARBONIFEROUS
Porphyritic granite		
Biotite-hornblende granite		
Marginal facies of biotite-hornblende granite		

ACKNOWLEDGMENTS

The author wishes to express his thanks to his colleagues in the Department of Geology, University of Nottingham, for many discussions on granites and for the pleasure of their company in the field on Jersey; to Dr. E. Mackerness for reading the manuscript of this paper. To Professor H. L. Hawkins, F.R.S., the author is greatly indebted for his continued interest and assistance in the author's researches in the Channel Islands.

EXPLANATION OF PLATES

PLATE 11

A. Dark biotite-rich bands and pegmatite developed immediately above a small dome of microgranite; south-west coast of Portelet Bay

B. Horizontal pegmatites above microgranite; south-west coast of Portelet Bay

PLATE 12

A. Parallel north–south faults displacing east–west porphyritic basic dykes in biotite-hornblende granite north of Île Percée, Noirmont

B. Granite traversed by fingers of dolerite sixty feet west of massive dolerite dyke, Corbière

PLATE 13

This series of photomicrographs, from sections BP 13–16 of the Bouilly Port traverse-illustrate textural variations within the porphyritic granite near to the microgranite, X.N. (× 8).

A. BP 13. This section, which marks the beginning of one of the cycles indicated in the traverse, contains abundant embayed quartz with inclusions of perthite, oligoclase and occasionally biotite.

B. BP 14. Compared with (A), quartz is less abundant, many quartz relics are in optical continuity. In this section the ferromagnesian minerals attain their maximum proportion and occur intersticially between the larger quartz grains and the felspars. Oligoclase is more abundant than in (A).

C. BP 15. Oligoclase is abundant in this section, forming distinct rims around perthite. In the larger plagioclase crystals optically-continuous quartz relics and some biotite flakes occur.

D. BP 16. Perthite, containing inclusions of both quartz and oligoclase, is more abundant than in the preceding sections while quartz and ferromagnesian minerals show their lowest proportions on this traverse. A marked decrease in the grain-size of the felspars also occurs.

PLATE 14

All photomicrographs X.N. (× 28).

A. Marginal granite, St. Aubin. Porphyroblastic quartz with many inclusions of the groundmass.

B. Sedimentary xenolith, La Carrière. Porphyroblastic quartz, with irregular margins containing a central part consisting of oligoclase, perthite, sericite and minerals of the groundmass.

C. Sedimentary xenolith, Le Fret. Granophyric intergrowth of quartz and perthite.

D. Marginal granite, Belcroute Bay. The groundmass of very fine-grained quartz, felspar, sericite and iron ores is characteristic of marginal granite near to the Pre-Cambrian sediments. Porphyroblastic quartz showing distinct fractures due to movement, with early oligoclase and perthite, also occurs. In the centre is a composite quartz showing pseudo-undulose extinction.

E. Sedimentary xenolith, La Carrière. Porphyroblastic oligoclase showing fractures and displacement by sub-parallel micro-faulting. The later perthite is relatively unaffected.

F. Sedimentary xenolith, Corbière. Relics of optically continuous quartz in oligoclase. In this photomicrograph there is a distinct suggestion of the hexagonal form of earlier quartz which has been replaced by oligoclase with albite lamellae parallel to one of the prism faces. Parallel growth lines, each slightly affecting the albite lamellae, also occur.

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DISCUSSION

DR. J. SUTTON congratulated the author on his paper. He would welcome further information on the attitude of the country rocks and on the shape of the lobes of granite at the north-east corner of the igneous intrusions. He enquired whether injection phenomena had been noted in the country rocks remote from granite outcrops. The speaker's interest in igneous activity in the Channel Isles had been aroused by what was displayed in Sark where the granites appeared to form sheets sandwiched in migmatitic and metamorphic rocks. The whole was folded about north–south axes and the presence of such features as felspar augen, boudins, elongated zoned ultrabasic balls, drag folds and a variety of small linear structures plunging with the local fold-axes led him to suppose that the migmatisation, metamorphism and folding were roughly contemporaneous. The speaker hoped that work on the forms of igneous and metamorphic rocks in the Channel Isles might assist in resolving the major stratigraphical problem of the area, i.e. that of deciding what dated from the Hercynian orogeny and what was pre-Hercynian in origin.

DR. A. K. WELLS complimented the author on the presentation of his paper. He noted some similarities, but many more differences between the south-western granites of Jersey, and those of the north and south-eastern complex, with which he was personally more familiar. In particular, megascopically they appeared to have little in common with the handsome and varied types quarried at Ronez and Mt. Mado in the north; but a more fundamental difference was the complete absence of rocks other than 'acid' rocks, apart from dykes. By contrast, in the north there was a wide range from ultrabasic through basic and intermediate; while in the south-eastern complex a wide variety of dioritic rocks accompanied the granites, microgranites and quartz-porphyries.

Although no information had been given concerning the form of the granite, the author had inferred tilting subsequent to intrusion to account for the differences between certain western and eastern contacts. Did this imply that the author believed the intrusion to be concordant, and that the present dips in the contiguous sediments resulted from post-intrusion tilting? To the speaker it seemed just as likely that the contrast referred to reflected original shape-characteristics of the mass, and did not indicate post-intrusion movement.

The speaker was impressed by the extensive textural alteration claimed to have resulted from the later intrusion of the microgranite. The thermal metamorphic effects of these granites were relatively slight, so far as the contiguous sediments were concerned; and it was therefore surprising that a microgranite, presumably dry and relatively inactive, should have induced complete recrystallisation and the development of a porphyritic texture in the surrounding earlier granite, over a wide area. It was quite certain that the more conventional explanation—of successive injections—could not apply to this case. In particular, did any contacts between the porphyritic and the earlier aphyric granites shed light on the subject?

On a point of detail, the speaker thought that the author may have misinterpreted a biotite-hornblende association shown on the screen. The inclusion of seemingly isolated patches of biotite in areas of hornblende, the former being in optical continuity, was interpreted as indicating the partial conversion of mica into hornblende; but the converse might be the case. Recently the speaker had described appinitic rocks from elsewhere in Jersey in which there was a constantly occurring three-dimensional association of biotite and amphibole, the former occurring with its basal pinacoid and cleavage direction perpendicular to the side-pinacoid, and parallel to the hypothetical front pinacoid of the earlier-formed amphibole. The view that the normal time-relationship (biotite after hornblende) holds in the case described by Dr. Henson is strengthened by the demonstration that porphyroblasts of alkali feldspar were in process of formation in these rocks.

A dark xenolith exhibited, and containing porphyroblasts of feldspar, was superficially identical with thousands occurring at Ronez and Fossé Vicq, and there produced from earlier more basic igneous rocks. But similar xenoliths formed from a wide variety of pre-existing rocks were well-known features of many other granites—Shap, Peterhead, Tregastel, for example, among the speaker's teaching material, and the convergence due to progressive granitisation was very striking.

MR. M. J. RICKARD said the Upper Sark Granite on Little Sark had a sheeted form, as mentioned by Dr. Sutton. The projection of the poles of the joint planes on a stereographic net showed a girdle about an axis parallel to the north–south lineation trend in the underlying country rocks of Sark. The orientation of minerals and of small hornblendic 'torpedo'-like inclusions were also parallel to this lineation trend. Did the joint planes in the Jersey granite give any indication of its possible form?

The hornblende-biotite granite of Little Sark had a coarser biotite-rich marginal phase at its base, separated by a narrow pegmatitic fringe from chlorite-muscovite schists. Across the narrow neck of land joining Little Sark to Sark this marginal phase narrowed considerably, whilst the mica-schists disappear altogether. The speaker asked whether the non-occurrence of the marginal phase in the north-west of this area could be due to stratigraphical differences resulting in the contact rocks being incapable of assimilation.

DR. A. F. HALLIMOND remarked upon the interesting additional examples of parallel growth between biotite and hornblende. He had described an intergrowth of this kind from the metamorphosed Tiree marble. There it seemed as if both the minerals might be growing at the expense of pyroxene, through the addition of water and alkali; the biotite cleavage was parallel with the *a* face of the hornblende and the minerals interpenetrated, like those illustrated by Dr. Henson.

MR. A. A. ARCHER wished to endorse the remarks of previous speakers, who had pointed out the different environment of the 'granites' of Sark. Dr. Henson had briefly mentioned some of the dykes which were intruded into the rocks he had described; could he say whether there were any acid dykes in the area, and if so what were their age-relationships to the other intrusions?

DR. A. E. MOURANT said that he had greatly enjoyed hearing the paper, not least because it reminded him of the days before the war, when he had himself attempted to map this area. He claimed no priority in the matter as he had not published his results, but he had mapped the outcrops of the three main granites described by Dr. Henson, though not that of the marginal type. The band of porphyritic granite between the coarse granite and the microgranite was such a constant feature that he was convinced it was not accidental, but was the product of some form of interaction between the other granites, or their magmas. On field appearances alone the impression was that, as one moved away from the coarse granite, the constituents became more and more separated by a fine-grained groundmass which ultimately passed into pure microgranite.

This was a different relation from that found between coarse granite and microgranite in other parts of Jersey. In the north-west, as Teilhard de Chardin and Pelletier had pointed out, a narrow band, rich in dark minerals, separated the two and was useful for mapping purposes. These writers had also reported such a band as occurring locally in the south-western granite, as also recorded by Dr. Henson.

As Dr. Henson had observed, impregnations and veins of magnetite were common in the western part of the granite area and included some quite large masses of the mineral. This mineralisation probably occurred at a relatively early stage of cooling of the granite, since well-developed octahedra of magnetite were present in some pegmatitic patches in it, while this mineral was rare in pegmatites in other parts of the island.

Dr. Mourant agreed with Dr. Sutton that there appeared to be a clear distinction between the modes of emplacement of the granites of Jersey, with their sharply-defined margins on the one hand, and those of Sark with their migmatisation on the other. In Guernsey there were gneisses and probably migmatites in the south, invaded to the north by unfoliated plutonic rocks somewhat similar to those of Jersey.

DR. HENSON thanked those present for their reception of the paper before replying to the many interesting points raised in the discussion. Like many of those present, the author had had opportunities of visiting the other Channel Islands and could, therefore, compare their igneous rocks and phenomena with those of south-west Jersey.

In reply to Dr. J. Sutton the author pointed out that the structures described in Sark were not found in this area of Jersey and that the axis of the granite mass in south-west Jersey was east–west. The sediments to the north were only very slightly metamorphosed and only at Mont Gras d'eau and La Rocco Tower were injection phenomena found away from the contact. These two localities were not in any sense remote from the granite outcrops, being just less than a hundred yards in each case. Thin granitic veins, traversing the sediments, occurred at both localities. In the St. Aubin area the sediments exhibited a regional dip of 60°–65° SE., although in addition minor folding, and some upward displacement by the granite during its introduction, had occurred. The granite lobes in this area were very clearly defined and cut across the sedimentary structures.

The author thanked Dr. A. K. Wells for his comments on the paper which were especially valuable in view of his own researches in Jersey over the past quarter of a century. In replying to Dr. Wells's first point, concerning the tilting of the mass, the author stated that the present dips in the sediments were not interpreted as due to post-intrusion tilting and that the contrast between east and west contact phenomena does, in fact, clearly reflect the original shape of the mass, although block tilting of the whole area, including the sediments, has also occurred. The author had considered the possibility of successive injections for the granites and, after field and laboratory studies, had come to the conclusion that essentially the complex consisted of two granite intrusions, each with a peripheral zone, i.e. contaminated marginal granite in the older granite and the porphyritic granite round the microgranite. Dr. Mourant's views, which he expressed at the meeting, also supported this interpretation.

Dr. Henson thanked Mr. Rickard for his comments upon the structures of Sark and the lineation of hornblende crystals in the gneisses. So far, in south-west Jersey, the joint planes had been mapped only between Corbière and St. Brelade's Bay. In the latter area, which is occupied by microgranite, the strikes of joint planes were predominantly east–west. This could be seen very strikingly from the cliffs above Beau Port.

The author agreed with Dr. A. F. Hallimond that the cleavage of the biotite in the parallel growths of biotite and hornblende was parallel to the *a* faces of the hornblendes. Some years earlier the author had discussed this mineral assemblage with Dr. H. Rutledge and, although the recent work at Ronez by Dr. Wells had shown clearly that other interpretations were possible, the author maintained the validity of the explanation now offered.

Mr. Archer has raised an interesting point about acid dykes which the author had not included in the paper. Only one acid dyke was found in the area, north of Belcroute Bay, which traversed the sediments in an east–west direction and showed a faulted western extremity. There were no major acid intrusives of the kind described by Dr. Wells at Gorez.

Finally the author thanked Dr. Mourant for his support regarding the probable origin of the porphyritic granite, based upon his own field observations. Also, it was of interest to hear of the basic bands found between the coarse granite and the microgranites in other parts of Jersey. There could be little doubt that these bands were similar in origin to those described at Portelet Bay. However, the author considered the mineralisation in south-west Jersey to be associated with the emplacement of the numerous minor microgranite masses and not with an early phase in the cooling history of the granite, as Dr. Mourant had suggested.

Chert: its Age and Origin in the Hythe Beds of the Western Weald

by D. W. HUMPHRIES

Received 10 December 1956

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ABSTRACT: Field and laboratory studies of the Hythe Beds of the Western Weald have shown that the chert contained in them was formed contemporaneously with the surrounding beds, and that the silica for the formation of the chert was derived directly from sea-water and not from the solution of the sponge spicules which are often, though not always, associated with the cherts.

Possible conditions for the deposition of chert in association with sandstones have been suggested.

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1. INTRODUCTION

THE PROBLEM of the origin of siliceous concretions, and, in particular, the origin of flint and chert, has long attracted the attention of many geologists. Most of the interest has centred round cherts contained in limestone rocks, such as the cherts found in the Carboniferous Limestone, and the flints which are restricted to the Chalk. Since cherts are much more common in limestones than in sandstones it is not surprising that the latter have been somewhat neglected. The present study, which forms part of an investigation of the sedimentary petrology and stratigraphy of the Lower Greensand of the South-West Weald (Humphries, 1953), is concerned with the development of chert in the sandstones of the Hythe Beds, and introduces factual details and conceptions which it is believed add to our knowledge of the whole problem.

At their type section in East Kent, the Hythe Beds consist of alternate layers of blue-hearted sandy limestone, the 'Kentish Rag' and brown loamy sand, the 'hassock'. Layers of each are about two feet in thickness. This type of lithology persists from the coast to about Maidstone where seams of spicular sandstone and some chert appear. Between Reigate and Dorking the stone bands fail completely and the beds are loams with pebbly sands at the top. To the south and west of Dorking these non-calcareous sandstones are traceable round the western end of the Weald as far as the River Arun, near Pulborough. Cherts are well developed around Leith Hill and to the north of Fittleworth. East of the River Arun the arenaceous facies is gradually replaced by the rag and hassock type and in East Sussex the stone bands are almost completely lacking.

In those areas where the chert is most strongly developed, notably round Leith Hill and north of Fittleworth, chert bands occur throughout the greater part of the Hythe Beds, but elsewhere they appear to be confined mainly to the upper part.

2. PREVIOUS LITERATURE

G. J. Hinde (1885) proposed an organic origin for the formation of chert, based on the occurrence of sponge remains in the arenaceous rocks of the Lower and Upper Greensands of the south of England. Hinde extended his observations to the Carboniferous Limestone series of Ireland and the corresponding strata in North Wales and Yorkshire, and claimed that sufficient sponges lived in the Carboniferous Sea to give rise to chert beds. Although Hinde is not specific, he implies that the chert was of subsequent origin—formed by replacement of the limestone after consolidation.

Prior to the work of Hinde, Hull & Hardman (1877) had postulated that the chert of the Carboniferous Limestone of Ireland was primary in origin, the silica having been derived directly from highly siliceous and felspathic rocks, and formed by the penecontemporaneous replacement of calcareous material.

The concept of the primary deposition of silica to form chert, without the intervention of a replacement stage, was developed by Tarr (1917) and supported by Lees (1926) and others.

Since the bulk of the published studies has been concerned with cherts associated with limestones and not with sandstones it is not proposed to extend this review of previous work. However, according to the source of the silica and the time of emplacement, the various modes of origin of chert may be summarised as follows:

(a) Inorganic silica:
  (i) Direct precipitation of silica gel to form *contemporaneous chert.*
  (ii) Migration of silica gel after deposition of enclosing sediment but before complete lithification—*penecontemporaneous chert.*
  (iii) Replacement of enclosing rock by silica, after lithification, to form *subsequent chert.*

(b) Organic silica:
  (i) Solution and re-precipitation of silica of siliceous organisms before complete lithification—*penecomtemporaneous chert.*
  (ii) Solution and re-precipitation of silica of siliceous organisms after lithification of enclosing sediment—*subsequent chert.*

The terms 'primary' chert and 'secondary' chert are frequently used and imply the direct precipitation of inorganic silica in the former case and the subsequent formation of chert, irrespective of the origin of the silica, in the second case.

3. THE ROCK TYPES

The rock types of the Hythe Beds which are associated with chert show continuous gradation from true chert to sandstone, but for the purposes of description it is convenient to divide them into four main groups, namely:

(a) True chert
(b) Sandy chert
(c) Cherty sandstone
(d) Sandstone.

Chert has been defined by Milner (1940) as 'a compact cryptocrystalline rock composed essentially of chalcedonic silica and microcrystalline quartz, characterised by a splintery fracture'. All the thin sections of chert examined have shown, between crossed Nicols, a fine-grained mass of mutually-interfering chalcedonic silica particles of brilliant blue-grey or yellow polarisation tints. Few of the sections are completely free from detrital quartz grains and these increase in number as the chert grades to a sandy chert and then to a cherty sandstone. No precise dividing lines have been drawn, but the boundaries are roughly at 5% and 50% sand grains, the remainder of the rock being chert. In hand specimen the chert is normally brown in colour and translucent, though occasionally it is grey and opaque. The sandy cherts generally have a 'sugary' aspect, and are usually pale brown in colour. This type grades into cherty sandstone, with little change in appearance, although the fracture tends to become less splintery.

Some, though not all, of the cherts contain traces of sponge spicules, the central canals of which are often filled with glauconite. Rare traces of other organisms also occur but are generally too diffuse to be identifiable. Scattered throughout many of the slides are minute grains of 'dust' which appear to be glauconite or limonite after glauconite. Occasionally finely-divided carbonaceous matter is present.

4. THE FIELD EVIDENCE IN THE HYTHE BEDS

All the available exposures in the Hythe Beds of the Western Weald have been examined, but only those which show significant features are described here.

The 'rag and hassock' facies is well developed in stone quarries at Dryhill, one and a half miles west of Sevenoaks Station (51/502533). Chert occurs as pink or purplish nodules in the limestone, the junction of the nodules with the limestone being quite sharp. The field evidence suggests they were formed by the replacement of the limestone, the silica being derived from spicules or other siliceous bodies in the hassock. In the eastern face of the main quarry there are occasional thin, almost vertical veins of chalcedony in the hassock, apparently in process of formation at the present time. The cherts of this pit are unlike any seen in the Hythe Beds farther west, since they are the only ones associated with limestone. However, cherts associated with limestone have been described by Richardson (1947) in the Bargate Beds round Churt and Hindhead. Richardson suggests that the calcareous stone bands of the Bargate Beds were decalcified, and that silicification followed rapidly upon the removal of the calcite. He believes that the process may still be in operation. In contrast with the evidence at Dryhill, the chert in the Bargate Beds is thought to have resulted mainly from silica precipitated by sea-water.

Cherts associated with sandstone are exposed in several small pits on Tilburstow Hill, south of Godstone (51/350520). On the east side of the Roman Road is a long narrow trench, apparently an old quarry, in which the beds consist mainly of hard sandstone and soft sand. The sandstones are well-jointed and at the south end of the trench, chert nodules about nine inches thick occur in the centre of blocks of sandstone. The junction between chert and sandstone is marked by a narrow transition zone.

A temporary exposure of some importance was seen at Hindhead at the site of a new reservoir (41/875373). The beds were mainly sandstones, with some cherty sandstones, and on the south side were two bands of chert each about one foot thick and about 6 ft. apart. Both chert bands showed undulations of large wavelength; about 30 ft. in the upper bed and about 15 ft. in the lower bed. The amplitude was between one and two feet in each case. The undulations are too large to be associated with wave or current action and may be due to differential compaction of the sandstones. Since the bands show no fracturing the chert must have been in a plastic state at the time of deformation.

The lower chert band terminated at the western end of the face in a remarkable manner, the chert swelling into a large concretion or nodule about 2 ft. in diameter (Plate 15, A). The cherty sandstones were depressed below the nodule and arched up over it. The nodule itself had a hard core of chert which was surrounded by a sandy layer enclosed in cherty sandstone.

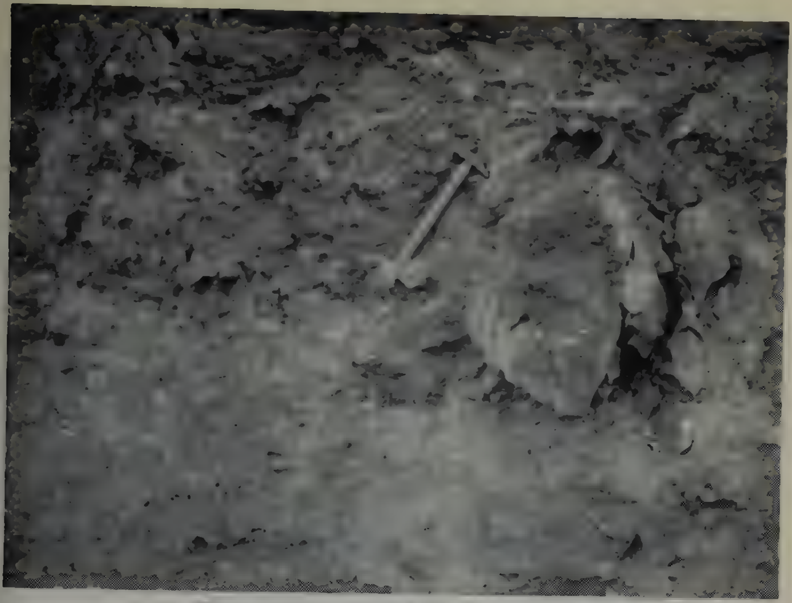
If the arching and depressing of the surrounding beds is attributed to differential compaction, one must assume that the chert nodule was already present and in a hardened state. Also it is possible that the still plastic gel was injected laterally from the silica of the main band, due to compression elsewhere, and arched up and depressed the surrounding beds. In the former case the chert must have been present before the consolidation of the overlying beds, and therefore before any considerable thickness had been deposited. Hence the chert must be considered primary and contemporaneous in origin. In the latter case the gel must still have been primary, though possibly penecontemporaneous. In either case there appears to have been movement of silica gel to give rise to the nodule. There is no evidence of secondary enlargement of the nodule after consolidation of the beds had occurred.

Probably the most important individual item of field evidence in support of a contemporaneous origin for chert is the slumped mass in the quarry on Combe Hill (41/800259) half-way between Rake and Rogate. About 12 ft. of medium grained, yellow sand occur at the top of the face, but the lower 30 ft. of the section are completely obscured. The sands are very gently current-bedded. At the top and near the bottom of the exposed face is a thin band of nodular spicular cherty sandstone with a somewhat cindery appearance. The sands below the lower stone band are richly glauconitic and are contorted by slumping. Vermiform markings pass through these slumped beds and suggest that slumping occurred very soon after the deposition of the beds and while they were still accessible to marine organisms.

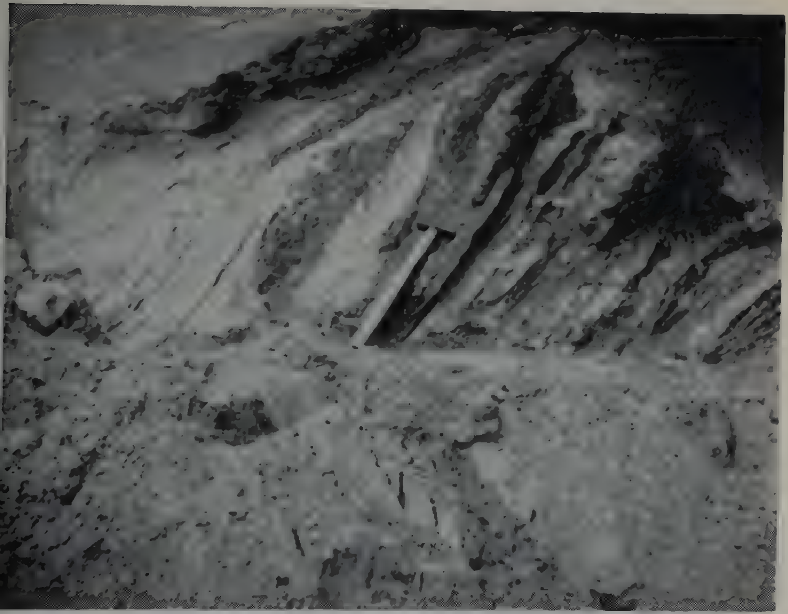
In the bottom right-hand corner of the face a mass of sandstone and strongly glauconitic sand is inclined at about 60°. The exposed part of this mass is triangular in shape, about 5 ft. across the base and nearly three feet high (Plate 15, B). A band of chert about 3 in. thick occurs in the mass and can be seen in Plate 15, B immediately to the right of the hammer. There is no doubt that the block is part of a slumped mass, since the sands above arch gently over it, and are only slightly disturbed. Vermiform markings penetrate both the top of the steeply inclined beds and the overlying sands. The presence of the chert band in the block strongly suggests that the chert is of primary origin and was sufficiently hardened to withstand movement very soon after the deposition of the overlying beds.

The main development of chert and cherty sandstone in the south-west Weald is in the area of Bognor Common and Flexham Park north of Fittleworth. Very many small pits have been opened, but in most cases the chert has been removed for road metal, and in only a few is it possible to examine true cherts. Most of the pits are shallow but this appears to result from the method of working, rather than from absence of chert at lower levels.

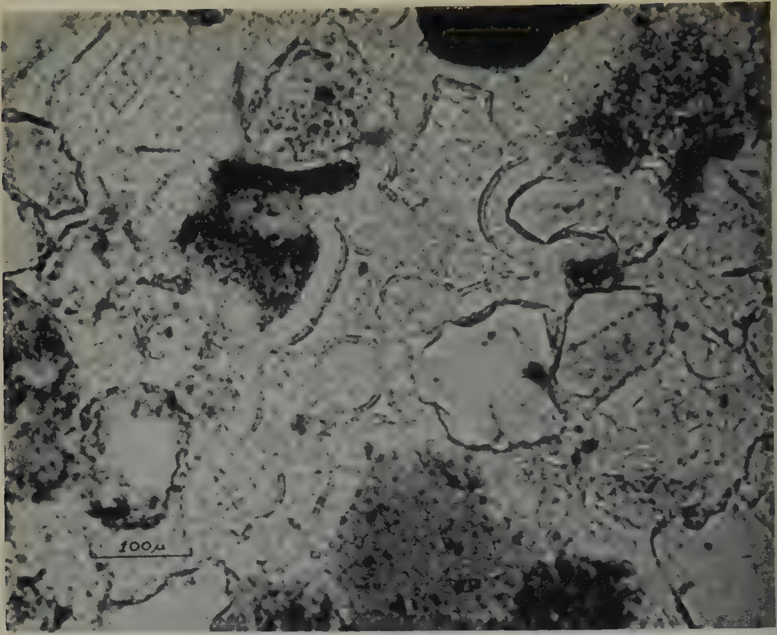
Information from quarrymen, and observation of the shape and distribution of the pits, indicates that the chert was usually present in roughly circular lenses varying in diameter from only a few yards to more than a hundred yards. The thickness varied between a few inches and three or four feet, although in one case the chert was said to have been twelve feet thick. The lenses of chert are not at a constant horizon and it is impossible to



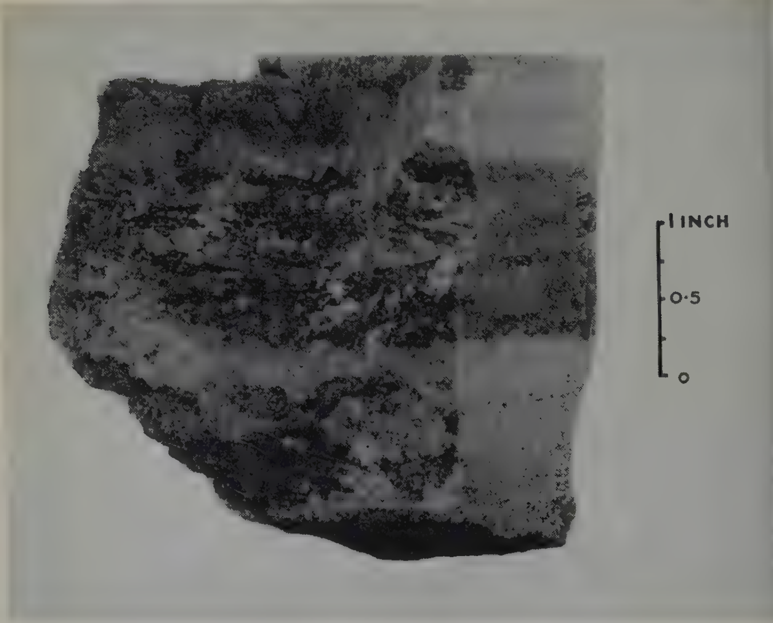
A. Chert nodule in temporary exposure, Hindhead



B. Slumped mass containing bedded chert, Combe Hill



A. Colloform structures in chert from centre of nodule shown in Plate 15, A



B. Thin chert band, grading into cherty sandstone above and below

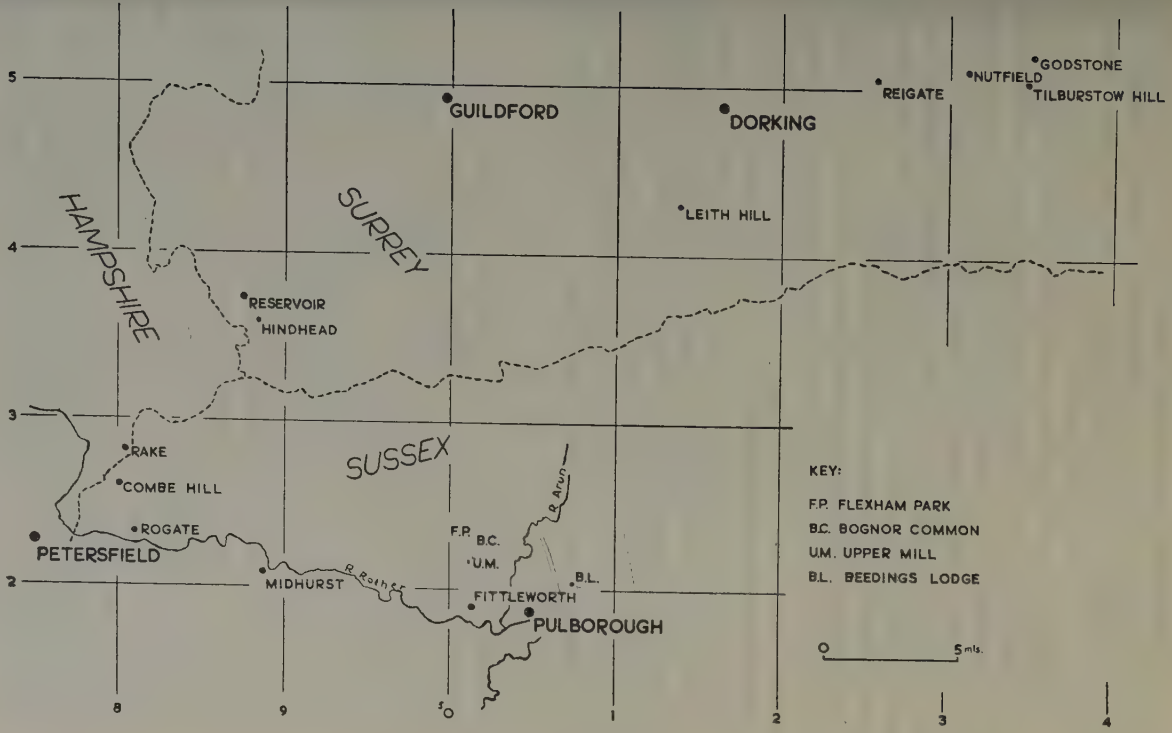


Fig. 1. Locality Map

correlate the beds from one pit to the next owing to the rapid variation in lithology. It was learnt from a quarry manager that the usual sign that the chert seam was dying out was the incoming of soft sands obviously rich in iron.

As an example of the variation in lithology of the beds, the quarry 600 yards west of Upper Mill (51/007208) and one and a quarter miles north of Fittleworth Church may be cited. In this pit twenty-nine distinct beds of sands, sandstone and chert occur in as many feet, but a single measured section cannot be said to be completely descriptive of the whole face in detail. The chert beds and beds of orange sand are more or less continuous, but both the soft sandstones and the cherty sandstones pass laterally into one another and also into orange sands. Small chert lenticles often occur in the cherty sandstones and sometimes in the orange sands. A noticeable feature of all the beds in this quarry is the almost complete absence of spicules, or hollow casts of spicules.

The rapid variation in lithology may be due in part to the weathering of glauconitic sandstones by circulating water to give orange sands. However, this seems unlikely in many cases since the immediately underlying beds are not stained by iron from the orange sands.

The lateral passage from green glauconitic sandstone to white cherty sandstone and orange sands suggests that there is a close link between the glauconitic sandstone and the presence of the cherty sandstone. Analysis of the glauconitic sandstone by the Dollar Integrating Micrometer Stage showed that about 31% of glauconite was present, which gives a value of approximately 9% for the iron oxide content of the rock. The iron oxide in the sand, estimated as the loss on leaching in dilute acid, was about 7%. It is reasonable to suppose, therefore, that the iron was entirely liberated from the glauconite and that the silica was available for cementing the sand. Owing to the diffuse and patchy nature of the chalcedonic silica in the cherty sandstone, precise determination of the amount of chalcedonic silica present was not possible. However, there would appear to be no doubt that the decomposition of the glauconite was responsible for both the iron and the silica of the orange sands and cherty sandstone respectively. This source of silica for the formation of chert is limited to the amount of glauconite present in the rocks, and is certainly too small to give rise to the massive cherts.

The most important characteristic of the small pits examined was the absence of any chert transgressing bedding planes which might suggest deposition from ground water circulating through a joint system.[1]

East of the River Arun, the Hythe Beds develop a calcareous facies containing many hollow casts of sponge spicules. Limestone beds containing sponge spicules should be the most likely places in which to find cherts formed by replacement, yet no cherts have been so found, nor are any recorded. This is a very strong indication that chert formation in the Hythe Beds has not been due to the replacement of limestone.

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[1] Dr. J. F. Kirkaldy informs the author that he has observed such a transgressive chert film in only one instance.

The Fuller's Earth pits in the Sandgate Beds at Nutfield were examined also in view of the description given by Newton (1937) '. . . a slightly sandy limestone with abundant glauconite and opaline siliceous material. This silica is derived from sponge spicules which occur in greater abundance and are easily recognisable with a hand lens.' In spite of conditions which would appear highly favourable to the formation of chert, namely an abundance of silica, often as opaline spicules, and a limestone available to be replaced, no sign of chert nodules or bands, or indeed any chertification, was seen in these pits.

5. THE PETROGRAPHIC EVIDENCE IN THE HYTHE BEDS

(a) **The True Chert.** The chert from the ellipsoidal nodule in the Hindhead reservoir is remarkably clear and largely free from detrital quartz grains. It consists largely of cryptocrystalline silica with a subordinate amount of microcrystalline quartz and shows 'colloform' texture (Plate 16, A).[1] There are many traces of organic bodies, most of which appear to be bryozoa, although there are a few remnants of sponge spicules the central canals of which are filled with glauconite. It appears that these spicules are actually hollow casts of spicules which have been filled with silica subsequently, since the glauconite threads and the walls of the casts are coated with very fine-grained chalcedony, while the remaining cavity is filled with much coarser material. This coarser infilling also encloses a number of ovoid chalcedonic bodies of low birefringence which are minute globules of silica gel in an early stage of crystallisation. Colloform structures in the silica matrix are distorted against spicules but do not penetrate them.

The quartz grains in the slide are more or less segregated into bands, but even in the bands the grains are not in contact and appear to be 'floating' in the matrix.

A section taken from the margin of the nodule is similar to that described above, but contains many more spicules, mostly in the form of hollow casts. Often these casts are filled with limonite in the form of minute isotropic translucent red granules.

Colloform structures are common in many of the cherts. The areas of spherical crystallisation are often similar in size to the transverse sections of spicules, and the former may readily be mistaken for the latter. However, the spicule may generally be recognised by the presence of glauconite in the central canal.

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[1] The term 'colloform' was coined by Rogers (1917) to describe the rounded, more or less spherical forms assumed by colloidal substances in open spaces.

If the circular areas are to be interpreted as cross-sections of spicules, it is necessary to suppose that the spicules were all oriented parallel to each other before inclusion in the matrix. That such an orientation could be almost perfect is unlikely. Furthermore, the circular areas vary in size, indicating that they are random sections cut through a number of spheres and not fortuitous sections cut exactly perpendicular to the long axes of a number of cylindrical spicules which are perfectly aligned.

Commonly the true cherts are without spicule remains, but this is not always the case. For example, the chert from Tilburstow Hill contains remnants of many spicules. The matrix of the rock consists of cryptocrystalline silica and encloses a number of quartz grains, all of which are 'floating'. Numerous spicules occur in longitudinal section. Some spicules are represented only by the glauconite infilling of the central canal, the wall merging into the cryptocrystalline silica of the matrix. In one slice, traces of 120 spicules were counted in 144 sq. mm. of chert. Throughout the slides of chert from Tilburstow Hill are vast numbers of minute cell-like bodies of high refractive index. These may be globules of silica, or possibly the resting spores of bacteria. No trace of calcite, or pseudomorph after calcite, has been observed in any of these cherts.

(b) **Sandy cherts.** Characteristic of this type are the grey and white sandy cherts of the pits in 'The Warren', one and a half miles north-east of Fittleworth. The grey rock appears to contain less detrital material than the white, largely consisting of cryptocrystalline silica with a small proportion of quartz grains fairly evenly distributed through the rock. A few siliceous sponge spicules occur both in longitudinal section and in cross-section. Occasionally the quartz grains have a layer of secondary quartz which is not in optical continuity with either the grain or the matrix. The matrix shows good colloform structures in those areas which are free from detrital quartz. The white sandy chert is similar in thin section, but is rather more porous.

(c) **Cherty sandstones.** With further increase in the proportion of detrital sand grains, the sandy cherts grade into cherty sandstones, and ultimately the sand grains become dominant, the chert taking on the rôle of a cement. As before, no precise boundary has been drawn.

(d) **Sandstones.** Generally the sandstones associated with the cherts are fine-grained and poorly-sorted. The grains are usually sub-angular to sub-rounded, with an average size of about 0.1 mm. Glauconite is commonly present in discrete grains of about the same size as the sand grains, but occasionally is disseminated throughout the rock. More rarely, glauconite is absent. The cementing material of the sandstone consists of a thin film of clay particles or limonite. In no instance was the matrix partly chert and partly some other material, such as a clay film.

Sponge spicules, or their hollow casts, often occur in abundance in the sandstone. Equally as often they are completely absent. It seems, therefore, that the presence or absence of spicules is not related to the presence or absence of chert.

(e) **'Floating' sand grains.** On several occasions reference has been made to quartz grains 'floating' in a chert matrix. By this is meant that the quartz grains are isolated from each other in the plane of the thin section. It is probable that many of these grains may make contact with other grains outside the plane of the section. The number of 'floating' grains in an arenaceous rock will depend on a variety of factors, including the shapes of the grains, the degree of sorting of the grains in accordance with shape and size, and the manner of packing of the grains. Also it will depend on the presence or absence of some material capable of holding the grains apart at the time of formation of the rock. In the case of the cherts this material could be either primary silica, deposited with the sand, or calcite which has been subsequently replaced, but there is no evidence that the Hythe cherts have been derived by replacement of a calcareous rock. Another possibility is that crystallisation of the silica between the quartz grains had forced them apart. There is, however, no evidence of disruption of the beds overlying the cherts which this would inevitably cause.

Graton & Fraser (1935) studied the packing of uniform spheres and have shown that, for a chance packing, 47% of the spheres are 'floating'. For particles that are not uniform in size or shape it is obvious that the number of 'floating' grains must be less. In an experimentally prepared sandstone Taylor (1950) found that approximately 17% of the grains were 'floating'.

The number of 'floating' grains in sandstones and cherts were determined by making a number of close traverses across the slides and counting all the grains as they passed the intersection of the cross wires of the microscope eyepiece.

The results for three typical specimens are given below:

Rock Type	Approximate size of grains	Percentage of Floating Grains
1. Massive glauconitic sandstone	0.1–0.15 mm.	3
2. Cherty sandstone	0.1–0.15 mm.	17
3. Sandy chert	0.1–0.15 mm.	46

Using the massive glauconitic sandstone as a control (since it contains no chert), it is obvious that the number of 'floating' grains in the other specimens is greatly in excess of the number in the sandstone whose origin is not in doubt. It is interesting to note that the number of 'floating' grains in the cherty sandstone is the same as that determined for an experimental sandstone by Taylor, and also that the number of 'floating' grains in the sandy chert is the same as the number in the chance packing of spheres as determined by Graton & Fraser. This may or may not be coincidental, particularly in the case of the sandy chert, since some cherts are devoid of sand grains. However, it may be argued that in the sandy chert the grains are neither spherical nor are they uniform in size or shape, and therefore the number of 'floating' grains exceeds the maximum theoretical value. Therefore the chert matrix must be either primary or a replacement of some pre-existing primary matrix. The presence of colloform structures in the chert implies that this was the original matrix.

In order to investigate the manner of packing of the particles, the number of contacts per grain was determined and the nature of the contact noted. The contacts were classified as tangential, long, concavo-convex, and sutured. The results for the three rocks used before are shown in Table I.

TABLE I

	ROCK TYPE		
	Massive Sandstone	Cherty Sandstone	Sandy Chert
Percentage of grains with			
No Contacts	3	17	46
1 contact	6	28	40
2 contacts	28	32	13
3 contacts	34	19	1
4 contacts	22	3	nil
5 contacts	5	nil	nil
Total grains	116	180	207
Total contacts	323	292	143
Contacts per grain	2.8	1.6	0.7
Percentages of Contact types:			
Tangential	74	74	81
Long	19	19	15
Concavo-convex	7	6	3
Sutured	1	2	1

From Table I it will be seen that the number of grains having no contacts, i.e. 'floating' grains, and the number having a single contact, increases from the massive sandstone to the sandy chert, but for grains having two or more contacts the number decreases. Furthermore, the massive sandstone has over 20% of grains with four contacts per grain, while the cherty sandstone has 3% and the sandy chert has none. The maximum contacts per grain (i.e. 5) was observed only in the massive sandstone. The implication of this must be that the massive sandstone is more closely packed than the cherty sandstone, which is itself more closely packed than the sandy chert. This is supported by the determination of the average number of contacts per grain, which are respectively 2.8, 1.6 and 0.7.

The work of Taylor has indicated that the amount of compression of a sandstone controls the numbers of the four types of contact. From Table I it is seen that the percentage of contacts of each type is almost the same in the three cases. This implies that the load on all three rocks has been approximately the same throughout their history, although it is probable that this is not a very sensitive test. While it is fairly certain that this was the case, the important point is that the grains must have taken up their position relative to each other very soon after deposition and any subsequent alteration must have affected all three equally. Since the packing of the sand grains is different in the three cases, any matrix must have been rigid before sufficient superincumbent load had accumulated to cause modification of the position of the grains. This implies that the chert matrix is primary in origin since no evidence for replacement of an earlier matrix has been found. If the chert was not rigid before any load had accumulated, presumably the gel would be squeezed into the surrounding sandstones (which are porous) and the packing of the sand grains would be such that there was no excess of 'floating' grains, nor could there be any chert free from sand grains.

Further indications that the chert is of primary origin are to be had from the measurement of the 'porosity' of the material. Here, 'porosity' is defined as the ratio of matrix to total rock, in order to make comparison with normal porosity determinations for sandstones possible. The volume of sand grains in the cherty sandstone used for earlier measurements was determined by a Dollar Integrating Micrometer Stage. It was found that the quartz and glauconite grains constituted slightly less than half the rock, the remainder being chert. The 'porosity' of the rock is thus about 50%. The generally accepted value for the porosity of newly deposited sands is between 39 and 49%, but this decreases considerably as the sand becomes compacted. Therefore it must be inferred that the chert was a primary component of the rock which prevented further compaction of the sand grains.

(f) **Sandstones and Limestones east of the River Arun.** East of the River Arun the Hythe Beds are represented by sandstones and limestones containing sponge spicules and casts, but are without massive chert.

(i) *Sandstones.* Typical of the sandstones of this area are the massive argillaceous sandstones exposed opposite Beedings Lodge (51/072203) two miles north-east of Pulborough. This rock consists of poorly graded quartz grains with an argillaceous matrix. Much opaque material is dispersed throughout the rock, and it is thought that this may be carbonaceous. Numerous well-formed hollow casts of spicules also occur. Although no solid spicules are present, from the form of the casts there is no doubt that these are exactly similar to those associated with the sandstones and cherts of the arenaceous facies of the Hythe Beds. The only evidence of chert in the rock is a few minute grains of chalcedonic silica. Apparently this material is primary in origin, since it is free from argillaceous particles.

(ii) *Limestones.* The limestones of the calcareous facies are sandy and occasionally contain casts of spicules replaced in calcite. The form of the cast is generally rather ragged, as though some of the matrix was removed in solution at the same time as the spicule was dissolved. The dimensions of these casts suggest that originally they were occupied by siliceous spicules.

In spite of the apparently ideal conditions for chert formation (that is, the presence of mobile silica in the form of sponge spicules and a readily replaceable material, calcium carbonate) no chert has been found.

6. SUMMARY OF EVIDENCE FOR THE PRIMARY ORIGIN OF THE HYTHE CHERT

From the foregoing description of the field and laboratory studies, the evidence in favour of a primary origin for the chert of the Hythe Beds is considerable. Apart from a few minor instances, undoubtedly the silica for the formation of chert and cherty sandstones was derived directly from sea-water, and not from the skeletal remains of siliceous sponges or other organisms.

The evidence may be summarised briefly as follows:

(i) Chert is involved at times in the contemporaneous deformation of beds:

(ii) Chert transgressing bedding planes in any way suggestive of deposition from ground water circulating through a joint system is almost completely absent:

(iii) No cherts have been found in, or are recorded from, the calcareous facies of the Hythe Beds, east of the River Arun, although the hollow casts of siliceous sponge spicules are abundant:

(iv) Colloform structures, indicative of a colloidal origin, are commonly present in the true cherts:

(v) Sponge spicules are not always present in the cherts, nor is there always any trace of their central canal preserved in some other material such as glauconite:

(vi) Spicule cavities are often perfectly preserved in a siliceous matrix, implying that the matrix must have been deposited and hardened before the spicule was dissolved. Therefore the silica from the spicule could not have contributed to the chert in which the cavity remains.

(vii) The number of 'floating' grains of quartz in cherty sandstones and in chert is substantially higher than in the associated sandstones

By the arguments developed earlier this must be due to the presence of a primary matrix of chert.

(viii) The 'porosity' (defined as the ratio of matrix to total rock) is much higher than in the associated sandstones, again indicating a primary matrix.

(ix) Calcite and pseudomorphs after calcite are completely absent from the cherts, cherty sandstones and sandstones of the Hythe Beds, indicating that the formation of chert is not a result of the replacement of calcium carbonate by silica.

7. DISCUSSION

The evidence set down above indicates that the chert owes its origin to the primary accumulation of silica gel on the sea bed. The silica is believed to have been precipitated from river waters either by electrolytes in the sea-water, or by organic agents, such as bacteria or algae of which virtually no trace remains. It is possible that the decomposition products of organisms in the sea may have assisted the precipitation.

Since this view is in complete opposition to that expressed by Hinde, further consideration of his 'Organic Theory' is necessary.

(a) **Objections to the 'Organic Theory'.** Hinde's evidence for the organic origin of the chert is meagre, since it is based on the rather insecure argument that the presence of an organic body of the same composition as the rock is a proof of derivation from such an organism. Furthermore, there is evidence that some chert of the Hythe Beds contains no trace of sponge spicules. It is interesting to note Hinde (1887) commented that most of the spicules seen in the thin sections of chert from the Upper Carboniferous Limestone of Ireland which were examined by Hull & Hardman (1877) were in transverse section. These authors had claimed that spicule remains were absent and it seems probable that Hinde misinterpreted the slides, and described as spicules circular areas due to spherical crystallisation (colloform structures).

In the discussion of a paper by Jukes-Browne on the 'Occurrence of Colloid Silica in the Lower Chalk . . .' (1889), Hinde is reported as having said that he was 'only interested in proving that the silica came from the spicules, and not in how it came from the spicules'. This raises the problem of the movement of silica from the spicule to the chert. Hinde and others have suggested that the true cherts are the result of the accumulation of a thick felted carpet of sponge spicules on the sea floor, the spaces between the spicules being subsequently filled with silica derived from the more isolated spicules in the immediate neighbourhood. In many cases the true cherts have an upper and lower layer of 'yellowish, porous, siliceous rock' (Hinde, 1885), the zones grading into one another. Numerous cavities, believed to be the empty casts of sponge spicules removed by solution after the consolidation of the beds, occur in the outer layers, and this dissolved-out silica is presumed to migrate both downwards and upwards to form a core of more solid chert. It is difficult to envisage a ground water or connate water system where such a movement could occur, but a more serious objection to this mechanism is the problem of the solution and re-precipitation of silica at points sometimes less than an inch apart (Plate 16, B). This would necessitate a very rapid change from an environment where solution of the spicules could occur to one where precipitation would take place. Since there is no evidence for the presence of limestone in association with the chert of the Hythe Beds, replacement mechanisms cannot be invoked. It might be supposed that the deposition of silica occurred by direct crystallisation on the walls of the spicules, but the presence of colloform structures implies the formation of chert from silica gel.

In connection with the migration hypothesis outlined above it is curious that only those spicules which are isolated from the main mass of spicules are dissolved. A further point to note is that the hollow casts of spicules described as occurring above and below the true chert are themselves made of chert, indicating that the spicules were themselves already surrounded with chert in a hardened state before they were dissolved out.

In view of the numerous objections to the 'Organic Theory' for the formation of chert in the Hythe Beds of the Western Weald which have been outlined here, some other mechanism must be postulated.

The field and petrographic evidence detailed earlier indicates that the chert was formed contemporaneously with the enclosing rock and that the silica was of inorganic origin. The source of that silica, its transport and deposition, must therefore be considered.

(b) **The source of the silica.** The ultimate source of the silica for chert formation would appear to be igneous rocks, especially under conditions of humid, tropical weathering. It seems that most of the silica is derived from the decomposition of silicate minerals; particularly those readily soluble in dilute acids. A further possible source may be the quartz grains of arenaceous and argillaceous rocks. This is difficult to prove directly but Murray & Irvine (1891) suggested that the process is assisted by alkaline sulphides resulting from the decay of organic material.

(c) **The mode of transference.** While the source of the silica can be directly indicated as the silicate minerals, a problem of greater magnitude concerns the removal of the silica to the point where the chert is to be formed. This problem is largely due to the very low solubility of silica in pure water.

According to Lehner & Merville (1917), pure water dissolves silica to the extent of 100 parts per million while the solubility increases in the presence of oxygen, carbon dioxide or 'humic acids'. Moore & Maynard (1929) give the maximum solubility as 20 p.p.m. Although these figures show that the solubility of silica under laboratory conditions is very low, the amount found in river waters is even less. About 15 p.p.m. is given as the average figure for the rivers of the world today, but even at this low concentration it has been estimated (Clarke, 1920) that every year more than 319 million metric tons of dissolved silica are carried by rivers to the sea.

It appears, therefore, that the presence of silica in river water can be explained without great difficulty, but the precise physico-chemical nature of this silica is still uncertain. At the low concentrations in rivers, it seems likely that the silica is transported as the hydrosol.

(d) **The precipitation of silica.** The experimental work of Taylor (1915), and Moore & Maynard (1929), has shown that the precipitation of silica by the electrolytes of sea-water can only occur when the concentration of silica is much higher than that occurring in river waters at the present day. Certain postulates can therefore be made to explain the supposed precipitation of silica in sea-water:

(i) That by some means the concentration of silica in colloidal solution in the sea was very considerably increased before precipitation could occur. It seems, however, that the constant evaporation of water to cause concentration of the silica would also cause a concentration of the mineral salts which one would therefore expect to be associated with cherts. This is certainly not the case with the Lower Greensand cherts, nor apparently with most other occurrences.

(ii) That some hitherto undescribed mechanism has been responsible for the precipitation of silica at very low concentrations. The precipitation of silica by siliceous algae has been suggested in place of electrolytic precipitation. At the present time these algae exist only in fresh water at a temperature greater than 60°C., and are unknown in sea-water.

(iii) That at times in the past the amount of silica carried in solution by rivers has been very much greater than it is now. This is certainly possible where cherts are associated with materials derived from a landmass in a late stage of the geomorphological cycle, or where chemical weathering predominated over mechanical weathering. These conditions, however, are not applicable to the Hythe Beds, in view of the abundance of arenaceous sediments.

Despite the difficulties in explaining the precipitation of silica from sea-water, there is every reason to suppose that such precipitation has taken place, in view of the evidence stated earlier of a primary origin for the chert of the Hythe Beds.

8. CONDITIONS OF DEPOSITION

The foregoing discussion has shown that the primary deposition of silica has been responsible for the formation of the chert of the Hythe Beds.

Since the rocks associated with the chert are often moderately coarse-grained sandstones, it is questionable whether silica could have accumulated to a sufficiently high percentage for precipitation to occur in the presence of comparatively swiftly moving water. There is no doubt, however, that the accumulation of chert free from detrital material sometimes occurred. Since the chert lenticles were never of any great extent, it is unnecessary to postulate the complete cessation of transport of detrital material into the basin of deposition. All that is necessary is that certain limited zones shall be free from detrital matter for a relatively short time and that the water shall be almost static. Such a condition could arise where a mass of vegetation existed. Where the vegetation was sufficiently dense most of the detrital matter would be screened out and the velocity of the water would be checked. Also it is likely that the decay of the vegetation would assist in the precipitation of the silica. The presence of traces of carbon in the cherts and cherty sandstones indicates the close association of plant matter with them. Crowded colonies of sponges would have a similar effect and in this case one would expect to find traces of sponge spicules in the cherts and in the surrounding rocks.

One may thus envisage the gradual establishment of a plant or sponge colony. As the colony spread, progressively less detrital material would reach the centre of the area where silica would accumulate in greatest proportion. The abundance of sponge spicules in some of the cherts and cherty sandstones suggests the density of growth would become so great, in time, that lack of food and oxygen, and accumulation of waste products, could cause the death of at least some members of the colony. At this stage detrital material would accumulate again over the whole area and the formation of true chert would cease. As the colony died out the accumulation of silica would diminish and sandstone would be formed. Where the accumulation of silica resulted from the screening effect of plants (e.g. algae) no fossil remains are likely to be associated with the chert.

Such an hypothesis would explain the presence of true chert underlain and overlain by cherty sandstone such as that illustrated in Plate 16, B. Also it would explain the lenticular form of the chert.

ACKNOWLEDGMENTS

The author wishes to express his thanks to Dr. J. F. Kirkaldy and to Professor L. R. Moore for their interest and encouragement in this research. Acknowledgment is made to the University of London and to Queen Mary College, University of London, for grants.

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Longitudinal Profiles of the Chiltern Streams

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Received 2 November 1953; read 1 April 1955

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ABSTRACT: From an examination of longitudinal profiles of the main valleys in the Chilterns a denudation chronology is constructed and then compared with the sequence derived from morphological studies of the Thames terraces in the type area. Up to, and in most cases including, the Winter Hill stage the comparison is satisfactory; beyond that stage the evidence from the profiles becomes meagre. The comparison is effected by means of the extrapolation of fitted logarithmic expressions and the result obtained is regarded as an empirical validation of this method of predicting relevant base-levels. The fact that the method cannot be extended to the upper reaches implies that the application is restricted and that in the lower reaches there are specifically favourable conditions.

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1. INTRODUCTION

THE CHILTERN STREAMS prove to have multicyclic profiles of the same general character as those of other streams in Southern England (Wooldridge & Kirkaldy, 1936; J. F. N. Green, 1946, 1949). A detailed analysis of the various profiles studied establishes an erosion-sequence which can be checked against the sequence already determined by morphological methods (p. 316). In order to compare the two sequences, use is made of the method involving the extrapolation of fitted logarithmic curves, formulated by O. T. Jones (1924), and refined by J. F. N. Green (1934). When the comparison is made, the result conforms with reasonable expectation, except that the profile-sequence reveals two stages which are not fully recognised in the morphological studies (p. 337). Despite this, the profile-sequence is not as complete as the morphological sequence for it only extends as far back as the Winter Hill stage. Recognisable forms of earlier stages are not represented in any of the profiles. The upper portions

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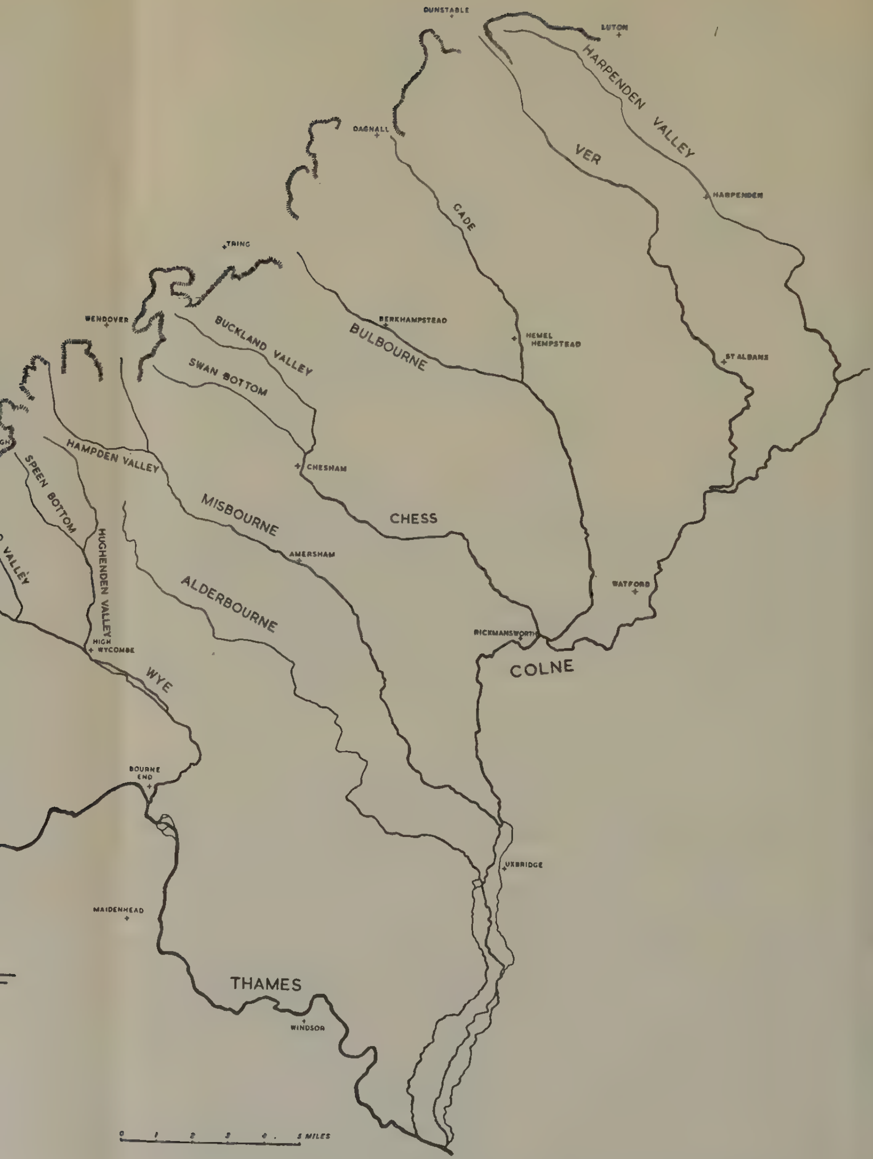
[1] See under Discussion of The Upper Reaches of the Chiltern Valleys, by E. W. H. Culling. *Proc. Geol. Ass., Lond.*, 67, 1956, p. 346.



system, showing streams and valleys for which longitudinal profiles have been determined of all the profiles examined are not amenable to the straightforward analysis that appears to be sufficient for the lower portions (p. 319): their interpretation is deferred, therefore. Although the primary object of this paper is descriptive, certain conclusions can be drawn as to the scope of profile-analysis in the study of denudation chronology. Also the degree of agreement obtained for comparison with the accepted morphological chronology can be taken as a provisional verification of the validity of base-levels predicted by logarithmic extrapolation.

The surveying of the nine stream-profiles concerned in this paper was carried out, between 1950 and 1951, by means of an aneroid barometer for which an accuracy of ±2 ft. is claimed. The aneroid traverses have been checked by two quickset level traverses and a full discussion of the probable limits of error involved is given in a thesis by the author (1953) which may be consulted in the Senate House Library, University of London.

The streams examined (Fig. 1) fall naturally into pairs: Hambleden Brook and Wye; Alderbourne and Misbourne; Chess and Gade, and Ver and Harpenden Valley. In the case of the second and third pairs, the mouths are so near that the altitudes derived from extrapolated curves can be compared directly. The Colne profile is used to correlate the sequences of the six eastern streams, and this result is correlated with that of the Wye and Hambleden Brook by assuming that the Thames at Mill End and at Bourne End is of equivalent stage to the one shown by the Colne floodplain at Uxbridge. Only the Wye profile is described in detail, being taken as an example. Results relating to the remaining profiles are summarised diagrammatically, except in those cases where a particular point or ambiguity calls for more lengthy discussion. The profiles are correlated in pairs, and a sequence of erosion-stages gradually built up entirely from these data. In effect the profiles are analysed into segments and correlated from the mouths upstream. This method involves the assumption that the record is both continuous and perfect in the sense that it shows all significant changes of base-level, and nothing else. The extrapolated curves are therefore used to substantiate the direct correlations. The final result is the most complete erosion-sequence that can be obtained from the profiles. This sequence is then compared with that obtained independently from morphological evidence relating the profile-segments to their relevant base-levels (in this case, the Thames terraces) by means of logarithmic curves.

2. TERRACE SEQUENCE

Whitaker (1889, I, p. 390), in the first systematic account of the drift geology of the Thames, recognises three terraces in the Maidenhead area: the Higher Terrace, Middle Terrace and Lower Terrace respectively, and distinguishes the alluvium as separate. This classification was adopted by the Geological Survey upon the re-survey of the London area on the six-inch scale (Pocock, 1903). The terraces were named from localities in the Maidenhead area and the drifts above the Higher (or Boyn Hill) Terrace were classed as fluvio-glacial gravels and the higher pebble gravels and drifts described as pebbly clay and sand. But White (1908) had already demonstrated the terrace nature of the fluvio-glacial gravels in the region west of Maidenhead. The threefold classification was adopted by Wooldridge & Linton (1939):

Stage I. Pebble Gravel
Stage II. Fluvio-glacial gravels
Stage III. Terraces up to the Boyn Hill Stage

Further, it was now known that there were more than three terraces in the lower group, and terraces had also been traced in the fluvio-glacial gravels. Sherlock (1924) and, later, Wooldridge (1938), followed a suggestion of George Barrow (1919) in discussing the former course of the Thames, and the relationship between the type-sequence of terraces in the South Buckinghamshire area, and the drifts of the Vale of St. Albans. Hare (1947) re-examined the gravel-spreads in the region west of the lower Colne and together with amendments due to work by Mrs. C. Sealy (1951), further west, in the Henley–Reading area, his results provide the sequence with which the present profile-sequence is compared. To the denudation chronology of the region established by Wooldridge and Linton (1939), Hare added two fresh terrace-stages, the Lynch Hill and the Black Park stages, and re-named the lower, and more clearly-defined spreads within the Lower Gravel Train, as the Harefield Terrace. Upon the basis afforded by Hare's work, Mrs. Sealy was able to extend the morphological survey of the Thames terraces in a westerly direction into the more difficult area of the Henley loop, and towards the Goring Gap. Here she found it necessary to divide the Taplow stage into two, and the Winter Hill stage into three distinct terrace-stages, respectively.

DENUDATION CHRONOLOGY OF THE CHILTERNS

A. Mio-Pliocene landscape
B. Early Pleistocene Bench and Deposits
C. Drift Stages
    Stage I. Pebble Gravel (*c.* 400 ft. O.D.)
    Stage II. Older Drifts
        'Terminal Rise'
        Higher Gravel Train—Leavesden Gravel Train
        Lower Gravel Train and Harefield Terrace
        Rassler stage
        Winter Hill I stage (Eastern Glaciation)
        Winter Hill II stage

Stage III. Black Park stage
Boyn Hill stage and Stoke Park Cut
Lynch Hill stage
Upper Taplow stage
Lower Taplow stage
Floodplain

The various stages recognised below the Taplow stage in the Lower Thames area are not listed here as they are not directly concerned in this research.

3. STREAM PROFILES

In the analysis of the profiles, the knick-points are found and the sections lying between them are provisionally regarded as of cyclic significance. These segments may or may not be of regular curvature. If they are, it will be possible to find a logarithmic curve which will fit the profile of the segment concerned. In practice almost every seemingly regular profile-segment can be satisfactorily fitted by a logarithmic curve of this form, within acceptable limits of error. If this proves possible in a given case, then the profile-segment is regarded as in some sense *graded*, though it is important to notice that, when so used, the term carries none of its usual implications.

On close examination, the graded reaches can be distinguished from the smooth curves presented by certain knick-sections in terms of the difference between the types of curve. Of the two, the graded profile has the lower gradient, or is part of a curve that has a lower gradient, which approaches the horizontal asymptotically. On the other hand, a knick-section of smooth profile is sigmoidal in form, and even if it does tend to approach the horizontal asymptotically it can be distinguished by its tendency to be symmetrical about a point of inflection. In a graded reach, the upper convexity is always relatively small, and in some segments appears to be absent. The objection that if the regular inter-knick sections are symptomatic of a graded condition, and all that that might imply, then surely the smooth curves of some knick-sections may be so regarded? Similarly, the corollary that both types of curve are sigmoid, and that to regard the graded curve as a simple concave curve is an error, cannot be dealt with here as they are matters outside the immediate scope of the paper. We will content ourselves solely with the question as to whether profile analysis can supply a denudation chronology which withstands comparison with that derived from morphology.

(a) Definitions

Knick-sections are breaks of slope in the general continuity of the profiles, and the major knick-section may be a point, a convex curve, or a complex reach of irregular or sigmoidal form. *Profile-segments* or *profile-*

sections refer to inter-knick reaches, whether they are graded or not, cyclic, or otherwise. The meaning attached to the term grade has been outlined above. A profile-segment that represents a halt in the intermittent negative change of relevant base-level—in this case, the Thames floodplain—is termed a cyclic, or erosion segment.

The term *floodplain* has been used to describe the valley plain in the ungraded reaches as well as in the graded reaches. Green's term 'temporary floodplains' (1946, p. 115) has not been employed, as all floodplains are temporary (J. F. N. Green, 1946, p. 96).

The term *logarithmic curve* refers to one given by an expression of the form

$$y = a - k \log (p - x)$$

A curve of this kind was used by Green in discussing the longitudinal profile of the River Mole (Green, 1934). To avoid needless repetition, the whole process of fitting a logarithmic curve of this type to a profile-segment and then extrapolating downstream as far as the present mouth of a river, in order to determine the predicted elevation of the curve at this point, is called *logarithmic extrapolation*. The height so indicated is referred to as the *extrapolated height*.

(b) Extrapolation

A graphical process has been used to fit the logarithmic curves to the profile-segments. This method, if less accurate, is much quicker than the orthodox mathematical procedure, even if a calculating machine is employed. To strive for deviations giving the least squares to several places of decimals is meaningless when the aneroid barometer survey is accurate to only ± 2 ft. What the method lacks in mathematical elegance is compensated by ease of application. At best, the predicted height is a median of an unknown and most probably asymmetrical distribution of probabilities. But graphical and statistical errors are slight when compared with those involved in the use of ill-founded assumptions. From purely theoretical considerations the use of logarithmic extrapolation should not give reasonable predictions of past base-levels (Miller, 1938), but nevertheless in the majority of cases it is found to do so. These empirical findings lead to the conclusion that either the theoretical arguments are mistaken or they do not apply or they relate to extreme cases where the discrepancies are negligible, or where the conditions are such as to result in a cancellation of the various errors involved. One instance where the method fails is in the analysis of the Colne profile. This is not to suggest that logarithmic extrapolation can be used without theoretical justification, but so far as the application of logarithmic extrapolation is concerned, the results which follow must be regarded to some extent as an empirical test of its validity as a method.

(c) Representations of Profiles

In every case the vertical exaggeration is one hundred times. For ease in recognition a number is allotted to each supposed cyclic segment, the numbering commencing at the mouth. Knick-sections are designated by a fraction composed of the numbers of the segments above and below. The lengths of the profile-segments are given in feet and distances from the mouth, in miles, are indicated along the lower border.

The general expression for the fitted curves is:

$$y = a - k \log (p - x)$$

where 'y' is the elevation of the profile, 'a' is a constant that defines the elevation of the curve as a whole, 'k' is a parameter inversely proportional to the greatest curvature, 'p' is the distance, in miles, of the vertical asymptote from the mouth of the river, or any other specified point, and is one unit distance above the point where $y = a$, and 'x' is the distance of any actual point on the profile from the mouth. In the representations, the numerical quantities 'a', 'k' and 'p' are given for each fitted curve. Thus: 100/50/7.55 represents

$$y = 100 - 50 \log (7.55 - x)$$

(d) The Profiles and their Interpretation

(i) *Wye*. The Wye is treated more fully than the other streams. A reproduction of the whole profile is given, together with profiles of three tributaries (Fig. 2). Up to 117 ft. O.D. the profile is regular and graded to the Thames floodplain. From 117 ft. O.D. to 122 ft. O.D. the profile exhibits the curve of a complex knick. The effects of rejuvenation are visible in the field. Above 122 ft. O.D. the profile presents a graded profile up to 150 ft. O.D. and is closely fitted by the logarithmic curve $y = 127 - 29 \log (3.27 - x)$, extrapolating to 112 ft. O.D. at the present mouth. From Bechet's Meadow (150 ft. O.D.) to Loudwater (174 ft. O.D.) the profile is steep and rather irregular. The anomaly at Ford's Mill (159 ft. O.D.) may be due to artificial raising of the floodplain above a mill pond. The fitted curve shows a rather low degree of coincidence, half of the surveyed points differing by more than 1 ft. from the theoretical curve. The knick at Loudwater is sharp, readily observable in the field and sited on the Chalk Rock outcrop which has delayed its retreat and is responsible for part of its sharpness. Above the knick the profile is straight, signifying aggradation in this section, where the Wye borders Kings Meads. The curve applied to the segment fits the upper part well and passes 3–4 ft. below the knick at Loudwater. Since the silting is unlikely to be due to natural causes, the knick shown in the profile is exaggerated, its true form being illustrated by the intersection of the two theoretical curves. The section from 194 ft. O.D. at Bowden Mill up to 221 ft. O.D. at High Wycombe presents

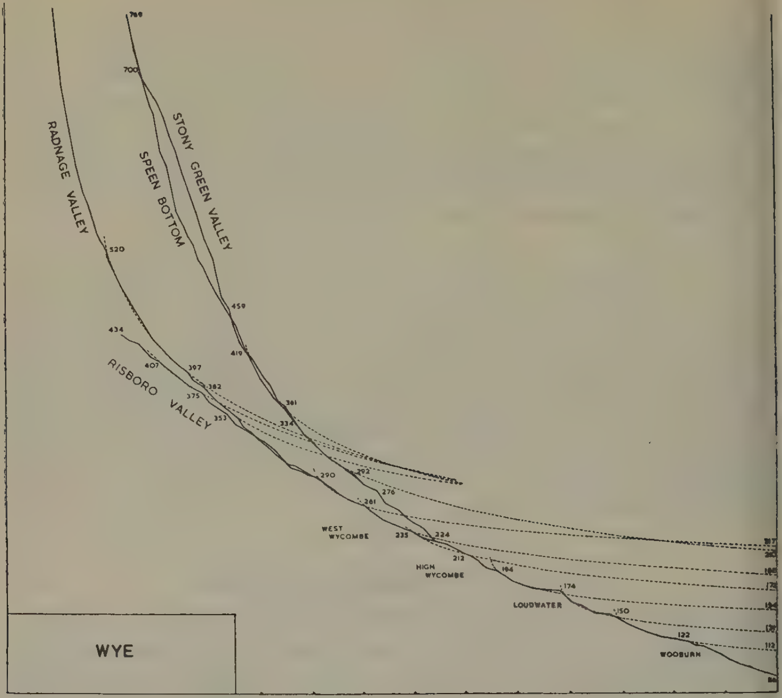


Fig. 2. Longitudinal profiles of the Wye Valley and its tributary valleys

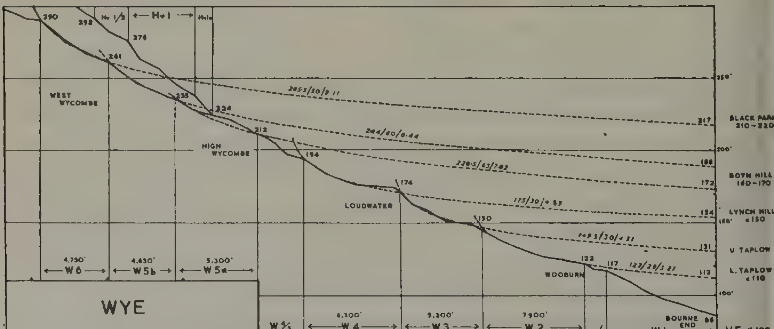


Fig. 3. Longitudinal profile of lower reaches of the Wye Valley

an irregular, and apparently ungraded, form. Above the Rye (209–221 ft. O.D.), which has been raised artificially in places, the Wye flows through the older parts of High Wycombe where buildings on the floodplain has made the survey rather more difficult. Originally the section was regarded as one long erosion segment. This view has some support in that a curve can be fitted with three points differing from the actual profile by more than one foot but with none differing by more than two feet. On comparing the profile with that of the other Chiltern streams, the graded nature of the former is more apparent than real. The full explanation is given on page 331, but it may be mentioned here that there are two erosion segments represented—212–235 ft. O.D. and 235–261 ft. O.D. The uppermost section of the Wye profile is occupied by the graded reach that extends to Flinthall Farm, West Wycombe (290 ft. O.D.).

(ii) *Risborough Valley*. The profile is mainly irregular, with only one apparently graded reach 375–407 ft. O.D., but the curvature is so slight that it can be fitted with curves of varying parameters. The Melbourn Rock outcrops just beyond the watershed (434 ft. O.D.) and the broad valley floor of the Princes Risborough Gap passes on beyond the obsequent dissection and apparently into the Lower Chalk Platform.

(iii) *Radnage Valley*. In the ascent to the scarp top at Chinnor Hill, the Radnage Valley exhibits two graded reaches, 349–382 ft. O.D., and 397–520 ft. O.D., above which point the profile becomes too steep to decipher.

(iv) *Hughenden Valley*. The Hughenden Valley profile reveals only one graded reach which can be fitted with a logarithmic curve (292–361 ft. O.D.). Above the Harrow (334 ft. O.D.) the valley splits into three branches of which two, Speen Bottom and the Stony Green Valley, were surveyed. These two head valleys are steep, and although they show knick-points and what might be cyclic reaches, only one section (Speen Bottom, 358–410 ft. O.D.) can be fitted with a logarithmic curve and the fit is not entirely satisfactory.

The Wye profile yields seven cyclic segments, but beyond the springheads interpretation becomes difficult. The four upper graded reaches which yield extrapolations converging at about 300 ft. O.D., near High Wycombe, cannot be relied upon as indications of relevant base-level, since the profile-segments are short and the extrapolations long, and the consequent selection of a logarithmic curve is arbitrary in some cases. What they show is that a further stage (or stages) is present in the Wye system above that represented by Wye 261–290 ft. O.D. and Hughenden 292–361 ft. O.D. Nevertheless, the continuity of the profile is broken immediately above these two segments and once this has occurred correlation between the Wye and any other profile is of dubious value. A similar change in the nature of the profile occurs in all the Chiltern valleys with the possible exception of the Harpenden Valley. In the lower parts of the valleys each section of the profile can be related, even if only tentatively, to a sequence of erosion stages, whereas the upper portions, although sometimes containing graded reaches, lack the required continuity and whole segments, if not the entire upper profile, cannot be related to the relevant local base-level. This paper is concerned solely with the lower reaches of the Chiltern streams, the upper reaches being considered in the second paper.

(v) *Hambleden Brook* (Fig. 4). The section above Flint Hall (213 ft. O.D.) can be fitted by either of two logarithmic curves, giving heights at the mouth which do not vary greatly (177–182 ft. O.D.), but one accords with the field evidence better than the other. The curve fitted between 239 and 269 ft. O.D. shows a poorer fit than the other, but does predict a low terrace, below 239 ft. O.D., which is actually present at Skirmett, and can be traced upstream until it merges with the floodplain at Poynats Farm (233 ft. O.D., G.R. 775904). The form of the ungraded section (213–239 ft. O.D.) strongly suggests that the gravel veneer has been stripped in advance of the main rejuvenation, in the manner suggested by J. F. N. Green (1946, p. 109).

(vi) *Delta Fan.* A peculiarity of the Hambleden Brook profile is the presence of a delta fan (White, 1908), and the resulting two graded segments, for one change of base-level. The delta gravels were deposited across the Thames floodplain on account of the coarse nature of the load which was carried by the Hambleden Brook. That small streams are able to build a delta across the floodplain of a larger river is evidenced by their occurrence in the gorge of the Colorado River, where freshets build fans that deflect

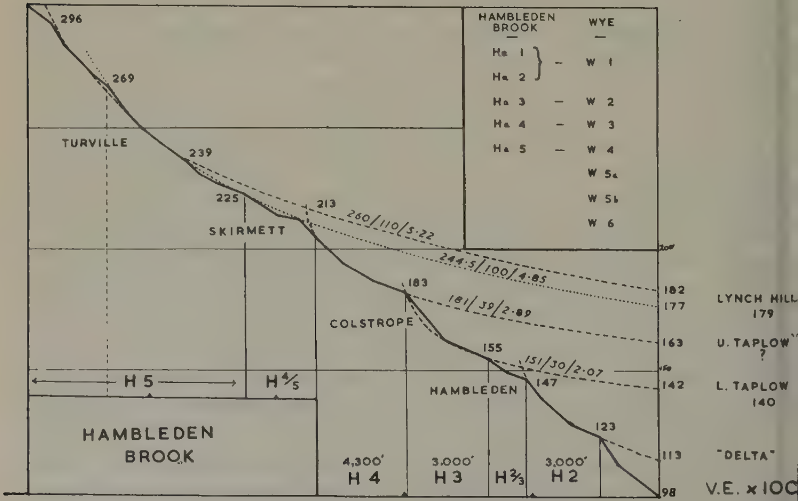


Fig. 4. Longitudinal profile of lower section of the Hambleden Brook

the main stream (Maxon & Campbell, 1935). The addition of a considerable load of coarse debris to a graded river will cause an increase of gradient. In consequence, streams coursing down from the Chilterns with such heavy loads as the Hambleden Brook once carried may be the explanation of the convexity of the Thames profile between Goring and Cliveden (Strahan, 1923).

Since the delta was built, the downsweep of the Remenham meander has truncated the fan and rejuvenated the brook, the incision having now reached the old river cliffs (123 ft. O.D.). For the effective production of an extra graded reach, such downsweeping meanders are necessary, but they must not be too close together, for the Hambleden Brook would be unable to become sufficiently graded to the delta surface to allow the profile to be modified above the delta. If such meanders were in close proximity, the Hambleden Brook would be subjected to continual minor rejuvenation and the lower profile would become irregular, probably developing a convex character. The intercalation of the delta gravels among the Thames gravels shows that the fan was built during a period of aggradation when the braided nature of the main stream rendered it unable to remove the delta fan. It was not until the Thames adopted its present meandering course that the delta fan became truncated.

The main conditions under which such features could develop would be provided during a climatic oscillation. A deterioration of climate would increase the load and gradient of the tributary stream. Also the Thames would steepen its channel by aggradation, and adopt a braided character, but this would render it unable to transport the load contributed by the Hambleden Brook, which would proceed to build out a delta on to the Thames floodplain. Nor would the braided Thames be able to destroy the delta by lateral erosion, though aggradation would bury the lower slopes and lead to the observed intercalation of delta and floodplain gravels. Upon climatic amelioration the Thames would develop a single meandering channel, probably degrading sub-parallel to effect a readjustment to the new conditions. The cutting of a Thames meander in the Hambleden Delta has resulted in rejuvenation and the production of a graded reach which persists in the profile. The three stages of rejuvenation, aggradation and truncation are illustrated in Fig. 5, together with a reproduction of the lower reaches of the Hambleden Brook. A further condition would be necessary; that the rejuvenation attendant upon the glacial eustatic change of sea-level did not reach the tributary confluence before the effective return to normal temperate conditions. If it did, the upper profile segment of the tributary would grade to the delta and also to the former floodplain of the Thames which would be left as a terrace by the rejuvenation, while the rejuvenated section of the tributary would relate to the new rejuvenated profile of the main stream. There is thus no extra graded profile-segment.

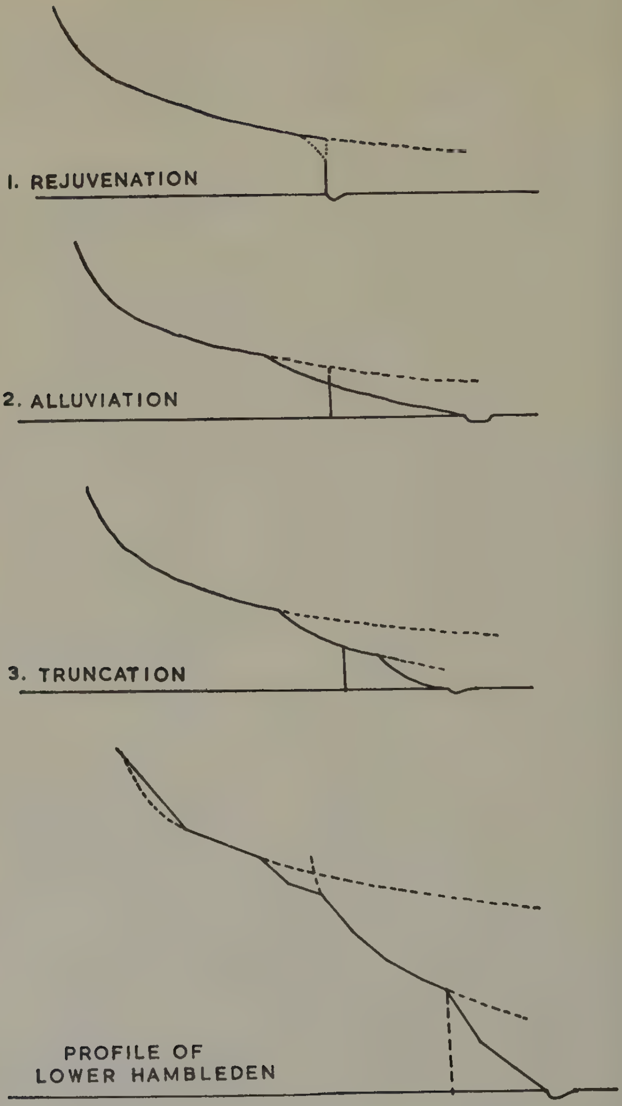


Fig. 5. Stages in the formation of two graded reaches from one change of local bas
level, as exemplified by the Hambleden Brook

The Thames has, however, returned to a normal erosional regime before the rejuvenation has reached the Hambleden Brook.

The delta of the Hambleden Brook indicates a period of periglacial conditions and the attendant rejuvenation is represented by a buried channel in the Lower Thames. This has resulted in the Hambleden Brook having two graded reaches for one major change of base-level, as represented by the floodplain of the Thames at Mill End. The extra reach is non-cyclic; it has no direct relationship to the buried channel in the Lower Thames. On a larger scale, the same process has been described by Mackin (1937). A period of downcutting in the Thames would produce a terrace feature along the north bank from Marlow to Henley similar to that found beside the Shoshone. Granted the same conditions, this process is liable to occur at any junction where a tributary is considerably steeper than the main stream. As climatic oscillations are known to have occurred more than once, the phenomenon may be repeated in the Chilterns. This indicates a grave defect in the method of correlating one profile with another by direct matching, which can be circumvented only by the use of logarithmic extrapolation.

(vii) *Hambleden Brook and Wye*. Assuming that no rejuvenation occurs in the Thames between Bourne End and Mill End,[1] and that therefore the two streams are graded to the same erosion stage in the Thames, then the two profile sequences can be correlated, as in the table (Fig. 4).

(viii) *Colne* (Fig. 6). In applying logarithmic curves to the Colne profile, close fits are difficult to obtain, for changes in the river channel and aggradation connected with interference of flow must be of frequent occurrence because the river is interrupted by gravel pits, lakes, weirs and connections with the Grand Union Canal. From 203 ft. O.D. to 214 ft. O.D. there is a shallow concave profile, with a weak knick at 214 ft. O.D. (London Colney), and above, a flat reach before the profile rises to Colney Heath. Here, either two erosion stages are present, or the flat reach is due to artificial aggradation. From the evidence provided by the Colne profile alone, there is no means of settling this question, but as the ambiguity is involved, in all the relevant profiles in one form or another, a full discussion is deferred.

As is readily apparent from extrapolations of curves fitted to the Colne, they are much in error if those of the tributaries are correct. Except for short distances, they give results which are too high. One reason for this is the nature of the Colne floodplain which is such as to render measurements inaccurate. Another reason is that since the Colne is not as large a river as it was, the depletion of volume has affected the profiles and decreased their curvatures. The parameters of the fitted curves are very small (21–33) when compared with the size of the valley. The question of profile change and its serious effects upon the validity of the extrapolation method must be postponed until the Colne profile can be analysed more fully.

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[1] An assumption verified by Strahan's profile (1923), and contrary to the opinion expressed by Barrow in his address to the Geologists' Association (1919, p. 15).

(ix) *Alderbourne and Misbourne* (Fig. 7). In the reproductions of the profiles of these two streams, the distance between their confluences with the Colne has been exaggerated by 3000 ft. to avoid confusing intersections of the profiles. The close proximity of the lower courses of these streams makes the correlation of their profiles an easy matter except for the sections below 188–189 ft. O.D. The two knick-points at 141 ft. O.D. and 149 ft. O.D. are regarded as of equivalent stage, not only from an inspection of the profiles but also because they can both be related to the same gravel spread at Denham. This leaves two stages in the Alderbourne (A 2: 112–126 ft. O.D. and A 3: 126–141 ft. O.D.) as equivalent to what appears to be one in the Misbourne (M 2: 120–149 ft. O.D.). However, the knick at 149 ft. O.D. proves to be spurious, being due to made ground; the true knick is at 159 ft. O.D. A logarithmic curve can be fitted to the profile 159–125 ft. O.D. by ignoring the made ground at 149 ft. O.D. and the silting in Denham Place 128–129 ft. O.D. This leaves a very small section of the profile 120–125 ft. O.D. as the representative of an erosion stage and also creates anomalies in the sections above. The correlation is beset with difficulties, but provisionally, both streams are regarded as having atypical elongated and shallow knick-sections (A 4/5 and M 3/4). The correlation is given in the table, Fig. 7, and the results of extrapolation provide no contradiction, but owing to the ungraded nature of many of the Misbourne segments, only two stages are represented by graded reaches in both streams.

It is assumed that there is no rejuvenation intervening between the Colne at Uxbridge and the Thames at Bourne End. Such an assumption is warranted by the evidence of Strahan's profile, and the fact that the Colne is building a delta below West Drayton. When the lengths of the profile-segments of the Colne are considered it seems unlikely that two are present below Uxbridge of which one is referable to a large shallow delta, for this would mean that the other section is inordinately short. Granted the validity of this assumption, then the lower reaches of the Wye, Alderbourne and Misbourne are of equivalent stage and can be correlated as in the table (Fig. 7).

(x) *Chess and Gade* (Fig. 8). The Chess yields a systematic record up to Chesham, and only one section, from Latimer to Sarratt Mill (255–213 ft. O.D.), fails to give a reliable estimation of the base-level to which it refers. From 213 ft. O.D. to 228 ft. O.D. the profile can be fitted by a logarithmic curve extrapolating to 193 ft. O.D. at the Colne, an elevation which proves satisfactory when compared with results yielded by the Gade. But an inspection of the profile reveals two straight reaches which indicate silting at the watercress beds at Sarratt Bottom (228–230 ft. O.D.) and at Chenies

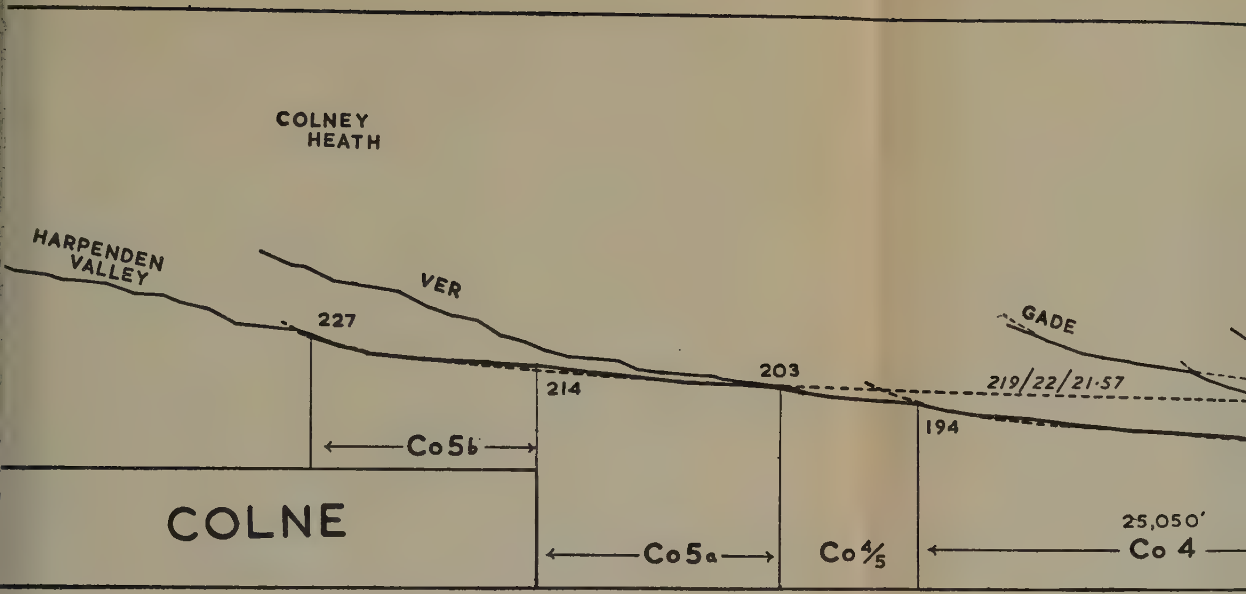


Fig. 6. Longitudinal profiles of the River Colne

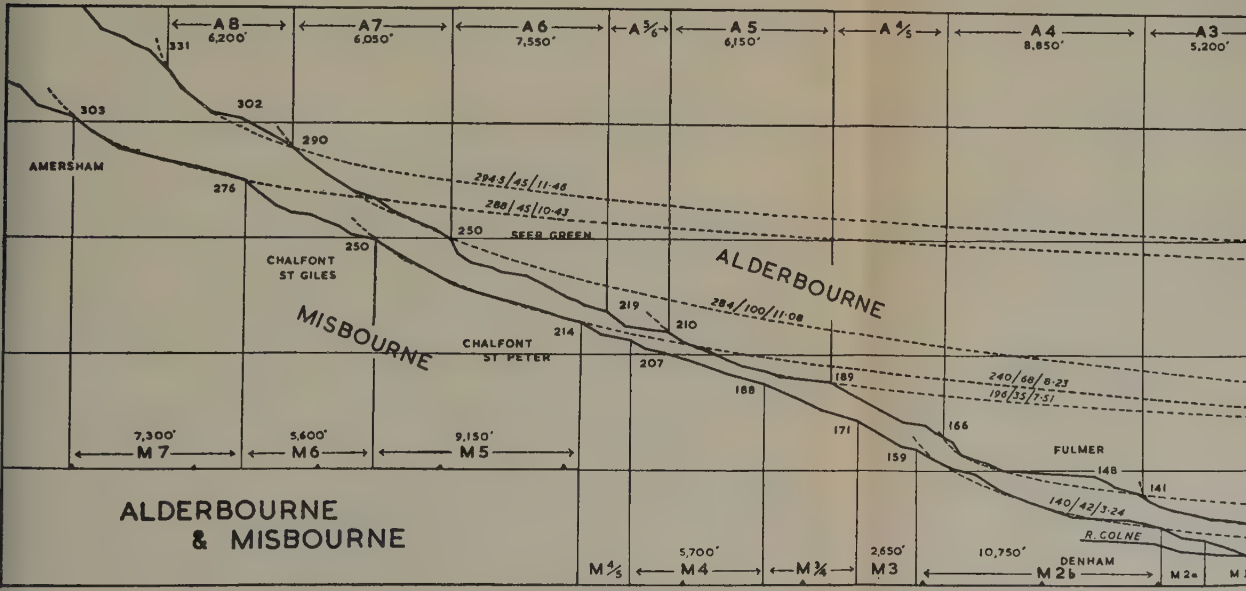
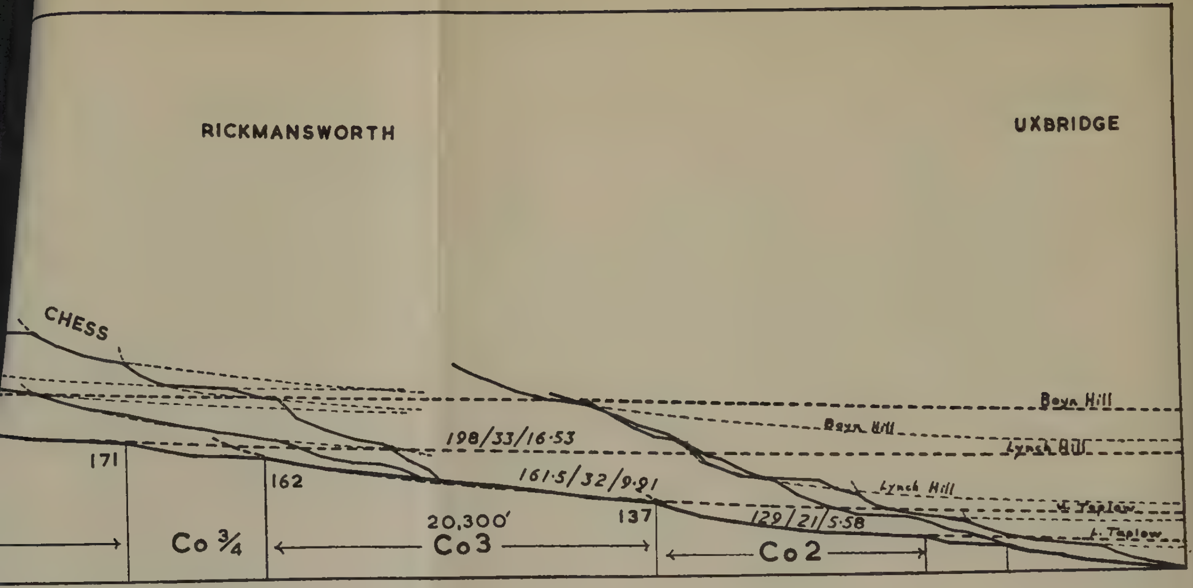
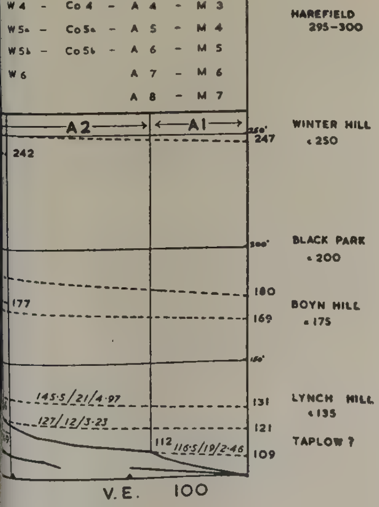


Fig. 7. Longitudinal profiles of lower reaches of the Alderbourne Valley and the Misbourne Val



d lower reaches of its tributary streams

WYE	COLNE	ALDER-B	MIS-B
W 1	Co 1	A 1	M 1
W 2	Co 2	A 2	M 2
W 3	Co 3	A 3	M 2
W 4	Co 4	A 4	M 3
W 5a	Co 5a	A 5	M 4
W 5b	Co 5b	A 6	M 5
W 6		A 7	M 6
		A 8	M 7



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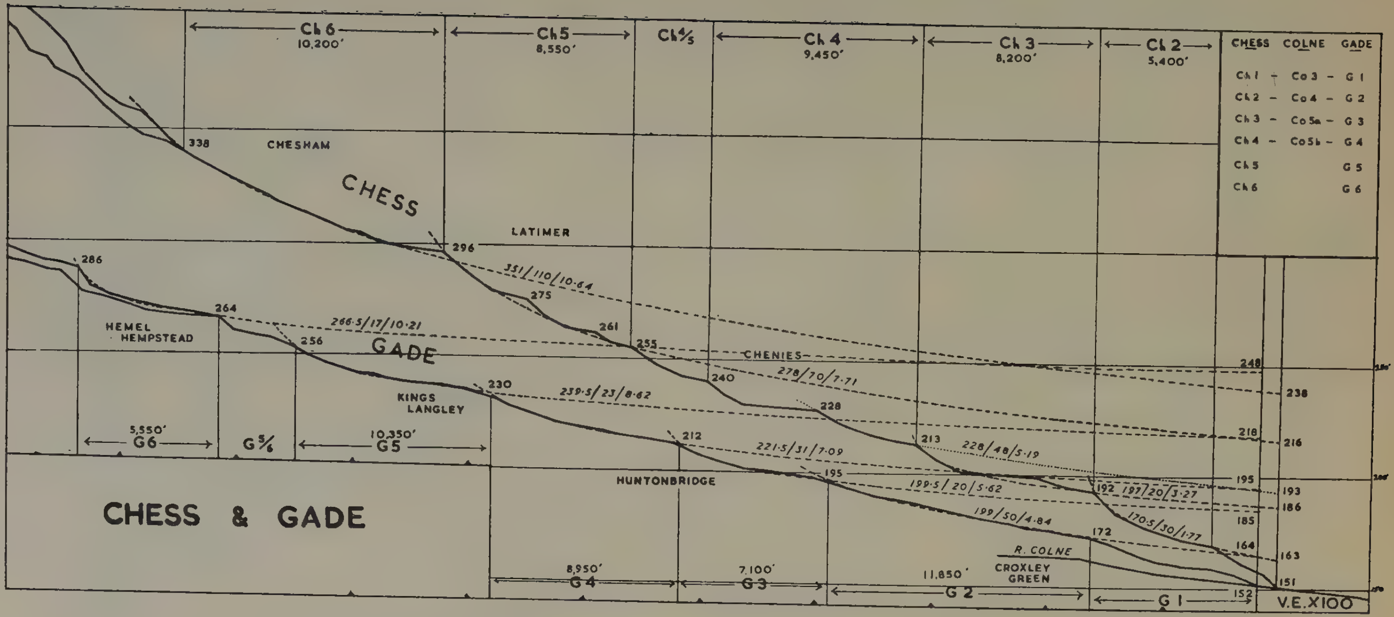


Fig. 8. Longitudinal profiles of lower reaches of the Chess Valley and the Gade Valley

Mill (240–241 ft. O.D.). Apparently the erosion-segment extends up to 240 ft. O.D., leaving 240–255 ft. O.D. as a knick-section. However, no logarithmic curve can be fitted to the section 213–240 ft. O.D. without considerable deviation from the profile. A poorly fitting curve, not shown in the reproduction for the section 222–247 ft. O.D., gives an extrapolated height at the Colne which is 20 ft. higher than that given by the alternative curve. The evidence from this segment cannot be used to build up an erosion chronology, for its consistent nature is due entirely to coincidence. Normally, the profile does not conform to a logarithmic character immediately below a silted reach but fits the profile above and below, as is admirably shown in the next reach upstream where, in the fitting of a curve, the two artificial lakes in Latimer Park (261 ft. O.D. and 275 ft. O.D.) can be ignored.

The respective confluences of the Chess and Gade with the Colne are close enough to cause no difficulties in the correlation of their profiles. Apart from the uppermost stage the extrapolated heights agree remarkably well and give clear support to the correlation based upon direct matching.

The knick-section in the Colne 161–171 ft. O.D. is almost a mile long and appears to be responsible for the 'double hang' of the two tributaries. The lowermost sections of the two streams grade to the 137–161 ft. O.D. segment of the Colne; while sections Chess—156–168 ft. O.D.—and Gade—159–169 ft. O.D.—relate to the complex knick-section of the Colne profile. They do not represent a former base-level related to an absolute or relative stillstand of sea-level. This is the second instance of a reach which is graded in the sense that it will tend to persist in the profile, but which does not refer to a cyclic stage (in this case, a Thames Terrace stage). The process is illustrated in Fig. 9.

Between the Misbourne confluence at 110 ft. O.D., and that of the Chess at 151 ft. O.D., the Colne profile reveals a knick at Denham (113–118 ft. O.D.) and another at West Hyde (137 ft. O.D.). The reach 118–137 ft. O.D. is the equivalent of the second of the Misbourne–Alderbourne stages and therefore the long reach 137–161 ft. O.D., above Rickmansworth, is related to the third of the pair (Fig. 6). The double hang feature of the Chess and Gade fixes their profiles in relation to the Colne sequence and by using these links one arrives at the correlation given in Fig. 8.

(xi) *Ver*. A logarithmic curve can be fitted to the reach 203–236 ft. O.D. if the break of slope at 216 ft. O.D. is regarded as wholly due to silting above the weir at the Park Street watercress beds. On the other hand, the weir may have been built at a natural knick-point, indicating the presence of two erosion-segments. The section above Kingsbury Mill (269–298 ft. O.D.) reveals an ambiguity. A curve can be fitted to the upper portion, but leaves the section 269–279 ft. O.D. as a rather long and shallow knick-section, while a further curve can be fitted 298–283 ft. O.D. and again between

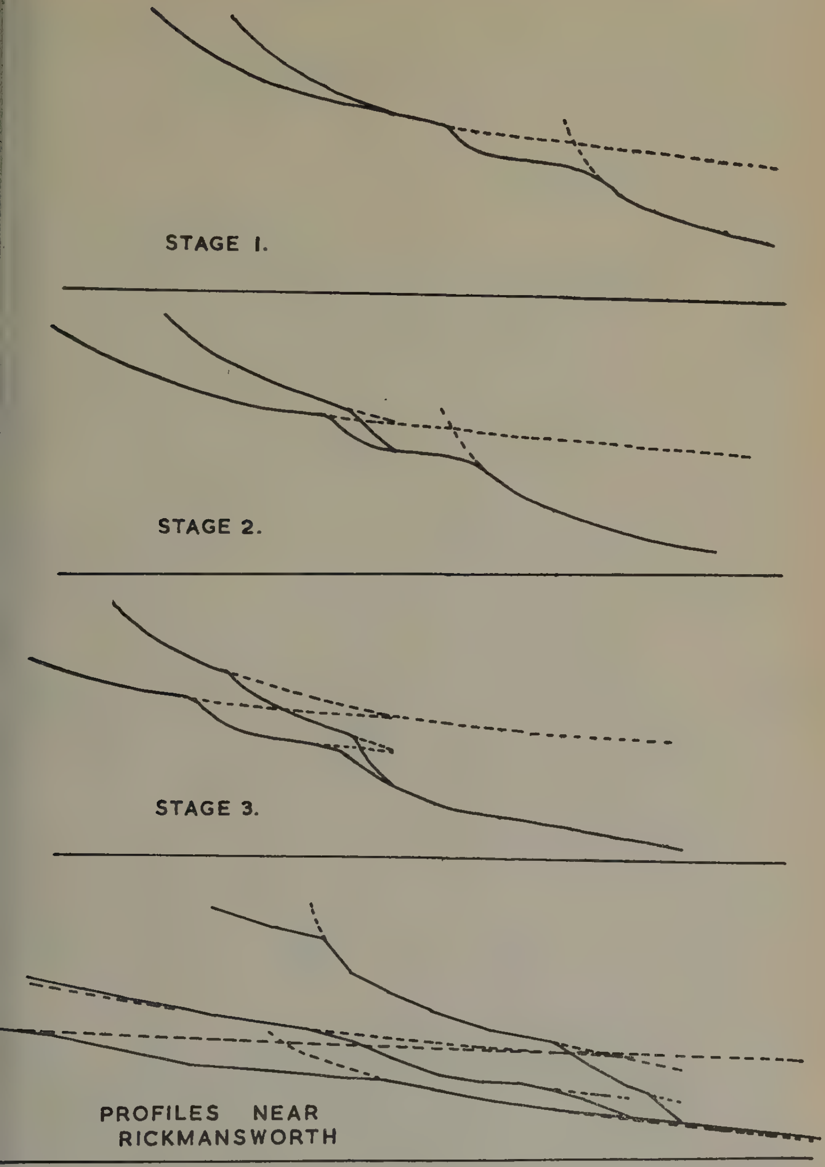


Fig. 9. Stages in the formation of two graded reaches in a tributary after rejuvenation by a complex knick-section, as exemplified by the rivers Colne, Chess and Gade, near Rickmansworth

279 ft. O.D. and 274 ft. O.D., when the anomaly 279–283 ft. O.D. may be ascribed to silting above Shafford Mill. Both curves are plotted in Fig. 10.

The Colne profile between the Gade confluence and the Ver (152–197 ft. O.D.), as in Fig. 6, consists of the upper portion of graded reach 137–161 ft. O.D.; knick-section 161–171 ft. O.D.; the long graded reach 171–194 ft. O.D., and the knick-section 194–203 ft. O.D.

On the other hand, above the Ver confluence the profile consists of part of the knick-section 194–203 ft. O.D., and the long reach between 203 ft. O.D. and 227 ft. O.D., where either one or two stages are involved. The lower portion of the Colne profile has been correlated with the Chess–Gade sequence already. In the upper portion, the knick-section 194–203 ft. O.D. is paralleled in the Ver profile, which is not surprising since these streams flow one on either side of the same floodplain. In the Ver, the section above the knick is represented by that between 203 ft. O.D. and 236 ft. O.D., and in both stream profiles there is some doubt as to the actual number of erosion stages present. Whether or not there are two, however, there is no doubt that the sections in the two streams are of equivalent stage.

(xii) *Harpenden Valley* (Fig. 10). Here the erosion-sequence is not as clear as in the other valleys examined. There are two gaps in the record from the lower course. The lowest of these, 231–253 ft. O.D., is classed as a knick-section but could possibly be a cyclic reach now disturbed by artificial, if not natural, agencies. The other reach (274–309 ft. O.D.) is taken as an ungraded cyclic reach, and not two such reaches separated at 289 ft. O.D., for at this point the convexity is likely to be due to aggradation by the tributaries at Nomansland Common. However, the record is neither continuous nor free from ambiguity, so correlation with the Colne profile is both difficult and doubtful. In view of the glacial history of the lower Harpenden Valley this is not surprising (Wooldridge, 1953).

Between the Ver and the Harpenden Valleys the Colne profile shows a knick-section 194–203 ft. O.D., and a long reach of either one or two stages at 203–227 ft. O.D. (Fig. 6). It is to the upper part of the long reach that the Harpenden Valley grades. The irregular section of the Harpenden Valley (231–253 ft. O.D.) is regarded as a knick-section and equated with that in the Ver between 236 ft. O.D. and 250 ft. O.D. The correlation of the Colne with the two tributaries is given in Fig. 10.

(xiii) *The Colne Profile*. The curve fitting the Colne segment 118–137 ft. O.D. yields 115 ft. O.D. at Denham, which is approximately correct although no extrapolation is obtainable from the Misbourne. Where the Alderbourne gives 109 ft. O.D., at Uxbridge Moor, the curve gives 113 ft. O.D. The next reach (137–161 ft. O.D.) is fitted by a curve indicating 130 ft. O.D. at Denham, where the Misbourne gives 119 ft. O.D., and 129 ft. O.D. at Uxbridge Moor, where the Alderbourne gives 121 ft. O.D. The third segment of the Colne is near enough to the mouths of the Chess and Gade

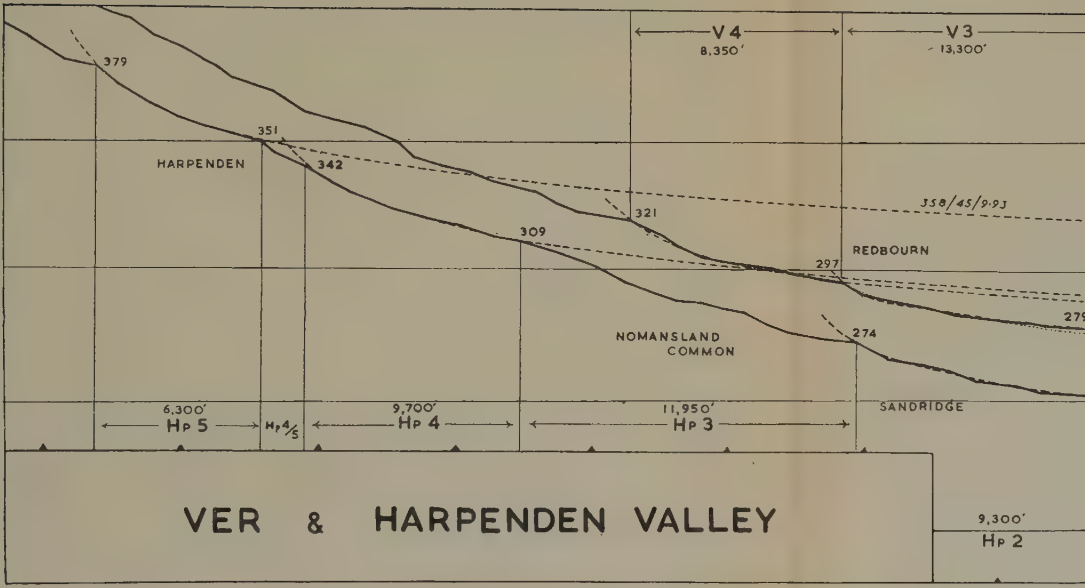
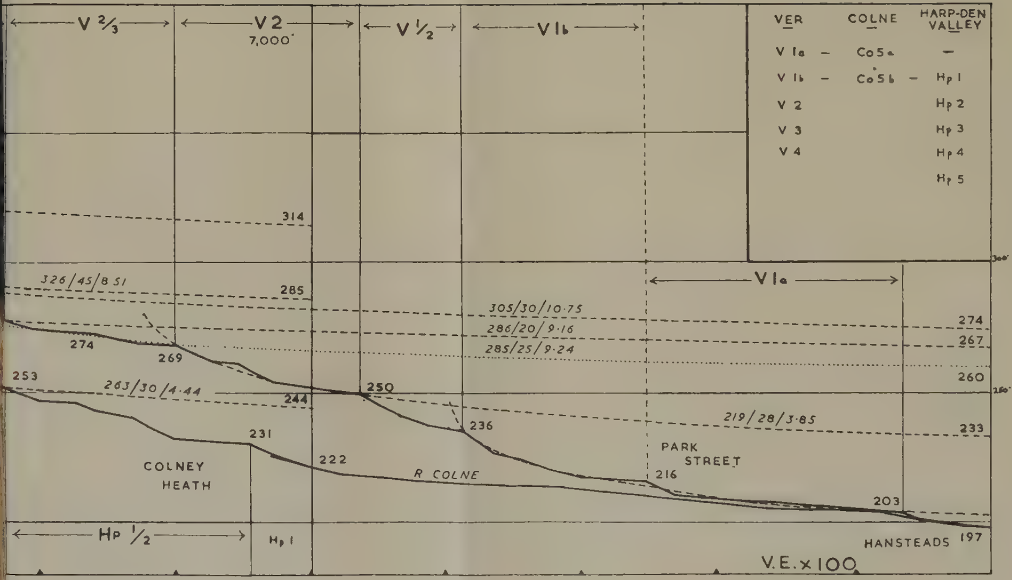


Fig. 10. Longitudinal profiles of lower reaches c



the Ver Valley and the Harpenden Valley

[*To face p.* 330

that any extrapolation error is small. However, downstream, at Uxbridge, the discrepancy increases to 27 ft. The upper segment 203–227 ft. O.D. is fitted by a curve which gives a height of 191 ft. O.D. at Rickmansworth. This latter falls within the range of height given by the two stages in both streams (Ch 3 and 4, and G 3 and 4). Downstream, at Uxbridge, the discrepancy for this curve is 19 ft.

The highest profile-segment of the Colne (203–227 ft. O.D.) is equated with the Ver section and both show evidence of what might be two erosion stages. These two segments are correlated with segments in the Chess, Gade, Misbourne and Alderbourne which are separated from the stage above by a small vertical interval. A further consideration might be mentioned. The curves fitted to the Colne have too low a parameter to give correct predictions of base-levels. The curve fitted to the uppermost segment has the longest extrapolation and with it one would expect the largest error. In fact, at Uxbridge the error is 19 ft., whereas that of the segment 171–194 ft. O.D. the error is 29 ft. This suggests that the curve concerned shows a spurious increase of parametral value, due to its being fitted to what are two separate erosion-segments, thereby reducing the extrapolation error. In consequence, the sections of the Colne and Ver above 203 ft. are regarded as consisting of two cyclic segments.

(xiv) *The Wye Profile.* As explained in Section 4 d (i) (p. 319), originally the segment 221–261 ft. O.D. was regarded as one stage. In the correlated sequence, this stage is equivalent to the Colne and Ver segments which have now been split into two, and the same mistake has been made in the case of the Wye. If the vertical intervals indicated between the two base-levels for the fifth and sixth stages in the correlational sequence are tabulated, the mean value is found to be about 10 ft. That is for every stream except the Wye.

River	**Vertical interval between indicated base-levels** ft.	
Colne	11	Interval between knick-point heights
Ver	13	
Gade	10	
Chess	—	*(No record)*
Misbourne	8	Taken together
Alderbourne		
Wye	36	(W 5 and W 6)

An enlargement of the Wye profile in the neighbourhood of High Wycombe is given in Fig. 11. The original curve is shown by a thin continuous line which fits the upper part of the profile but deviates at 235 ft. O.D. and 225 ft. O.D., though never by more than 1.5 ft. If, however, the profile represents two stages, then the point 235 ft. O.D. is the most probable site of the separating knick. The upper portion (235–261 ft. O.D.) can be fitted almost perfectly by a logarithmic curve, but the lower section proves to be more difficult in this respect. A curve of low parameter (38) gives a poor fit and its extrapolation intersects that of the curve relating to the upper portion. If, however, the profile below 226 ft. O.D. is ignored, and a curve fitted to the short section 226–235 ft. O.D., its extrapolation passes below the profile 226–212 ft. O.D., where it again meets the profile. As the section 226–235 ft. O.D. is short, it can be fitted by a variety of curves with parameters ranging from 57 to 70. The chosen curve cuts the profile at 212 ft. O.D. (where there is a slight concave inflection of the profile), and leaves the knick-section (194–212 ft. O.D.) as an almost perfect sigmoid curve. This interpretation implies that the floodplain has been raised 4 ft. to 5 ft. at High Wycombe and that the steep gradient of Wycombe Rye is due to this artificial elevation.

The two curves give extrapolated heights at the Thames which differ by 16 ft. The two erosion stages are clearly shown by the Hughenden Valley:

Wye			**Hughenden**		
W 5a	...	212–235 ft. O.D.	Hu 1a	... ...	225–238 ft. O.D.
W 5b	...	235–261 ft. O.D.	Hu 1b	... ...	238–256 ft. O.D.

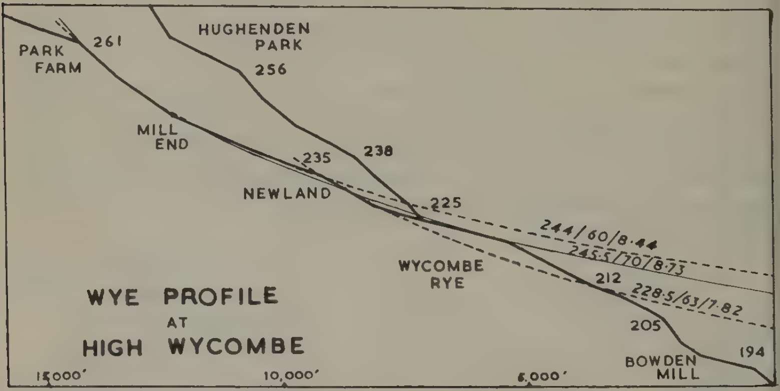


Fig. 11. Longitudinal profiles of the Wye Valley and the Hughenden Valley in the neighbourhood of High Wycombe

4. DENUDATION CHRONOLOGY DEDUCED FROM STREAM PROFILES

A study of the profiles so far discussed has yielded a chronology of eight stages, including the Floodplain stage, and these are numbered in the accompanying table. The truth of the correlations depends upon two assumptions. First, that no rejuvenation intervenes between the Colne at

Uxbridge and the Thames at Mill End—an assumption which is almost certainly correct. Second, that no extra stages are either interpolated or omitted from any of the profile-sequences. This assumption demands a theoretical treatment for its full justification, but logarithmic extrapolations gives a partial check. Each profile stage represents a period of relative stillstand in the position of the Thames profile. As the Thames terraces are of the cut-and-build variety, each terrace stage was brought to a close by a gradual rise in the level of the Thames profile owing to aggradation. This gradual rise was terminated by a sharp drop, attendant upon rejuvenation, and this left the aggraded deposits as a terrace. Whereas the tributaries remained in grade with the gradually rising Thames profile, they failed to do so for the rapid debasement that closed the stage. Therefore the tributary segments relate, not to the cut benches on which the terrace deposits rest, but to the aggraded terrace surfaces. It is with the heights of these surfaces, therefore, that the extrapolated heights must be compared.

5. CORRELATIONS WITH THE TERRACE SEQUENCE

Verification of the predicted profile-sequence is a possibility for only the four western streams. Owing to their glacial background, and to the paucity of terrace remnants, a complete verification is not forthcoming for the four remaining eastern streams. However, the latter do provide valuable corroboration and the results, as a whole, are coherent up to the Winter Hill stage, but in the analysis of the eastern streams the results obtained from the western streams must be employed. Thus, the thesis rests entirely upon the evidence collected from the western streams, i.e. the Hambleden Brook, Wye, Alderbourne and Misbourne.

(i) *Hambleden Brook*. The interpolated heights of the Thames terraces at Medmenham, as given by Mrs. C. A. Sealy, are given in Fig. 4. A discrepancy is apparent when these heights are compared with the extrapolated heights. The elevation of 140 ft. O.D. suggested by her as that of the Upper Taplow stage appears to be that of the Lower Taplow stage.

(ii) *Wye*. The elevations of the terraces given in Fig. 3 are taken from Hare (1947), with modifications due to Sealy (1951). The gravels south of Cookham Station (G.R. 887850) are regarded by Mrs. Sealy as being of Lower Taplow stage, and this agrees better with the evidence provided by the profile, for two stages are represented below the Lynch Hill. In the correlation an extra stage (W 5a) is found in the record yielded by the profile and this proves to be the one which was first overlooked (p. 331). The postulation of an extra (Lower) Taplow stage is supported by the fact that its omission results in each extrapolated height having an altitude suited to the next terrace stage above—an unlikely coincidence.

Table of Erosion Stages derived from analysis of Stream Profiles

Stage	Hambleden Brook	Wye	Alderbourne	Misbourne	Colne	Chess	Gade	Ver	Harpenden Valley
F/P	Ha 1 & 2	W 1	A 1	M 1	Co 1	—	—	—	—
2	Ha 3	W 2	A 2	M 2a	Co 2	—	—	—	—
3	Ha 4	W 3	A 3	M 2b	Co 3	Ch 1	G 1	—	—
4	Ha 5	W 4	A 4	M 3	Co 4	Ch 2	G 2	—	—
5	—	W 5	A 5	M 4	Co 5a	Ch 3	G 3	V 1a	—
6		W 6	A 6	M 5	Co 5b	Ch 4	G 4	V 1b	Hp 1
7		W 7	A 7	M 6	—	Ch 5	G 5	V 2	Hp 2
8		W 8	A 8	M 7		Ch 6	G 6	V 3	Hp 3
9		—	—	—		—	—	V 4	Hp 4
10								—	Hp 5

(iii) *Alderbourne and Misbourne.* The terrace elevations shown in Fig. 7 are taken from Hare (1947), but the Taplow stage is unrepresented in the Colne Valley. The extrapolated height for A 7 (Black Park) is too low, while the correlation of stage A 4 with the Lynch Hill cannot be taken as evidence in support of the profile-sequence, for the fitted curve was selected with the correlation in view. As in the Wye profile, an extra stage (either 5 or 6) is suggested by the profiles.

Before proceeding to a consideration of the four eastern streams it will be convenient to list the stage numbers against the terrace sequence, in the following table:

Terrace stage	**Hambleden Brook**	**Wye**	**Alderbourne**	**Misbourne**
Floodplain	1 (Ham 1 & 2)	1 (W 1)	1 (A 1)	1 (M 1)
Lower Taplow	(2) ? (Ham 3)	2 (W 2)	2 (A 2)	2 (M 2a)
Upper Taplow	(3) ? (Ham 4)	3 (W 3)	3 (A 3)	3 (M 2b)
Lynch Hill	4 (Ham 5)	4 (W 4)	4 (A 4)	4 (M 3)
Boyn Hill	—	5 (W 5)	5 (A 5)	5 (M 4)
		6 (W 6)	6 (A 6)	6 (M 5)
Black Park	—	7 (W 7)	7 (A 7)	7 (M 6)
Winter Hill	—	—	8 (A 8)	8 (M 7)

If the elevation of 140 ft. O.D., listed by Mrs. Sealy, is regarded as referring to the Lower Taplow stage, and not the Upper Taplow stage, the inconsistency shown under Hambleden Brook is removed. The significance of the two stages relating to the Boyn Hill stage is discussed later, but it may be remarked at this point that this inconsistency between the profile-sequence and the terrace sequence in the same place in every relevant profile is strong support for the validity of the profile chronology. It confirms the re-interpretation of the Wye profile (p. 331) and its regular occurrence suggests a real inconsistency and not either a fault in the evidence or a mistake in the analysis. The consistent nature of the rest of the table justifies the conclusion that the numbering of the profile stages corresponds with that of the terrace stages if an extra stage is inserted either above or below the Boyn Hill stage.

(iv) *Colne.* When compared with the heights given by extrapolation from the tributary profiles, those derived from the Colne give values which are too high. As the evidence from the tributaries is consistent, when compared with the actual terrace heights, the error would seem to reside in the curves fitted to the Colne. This error increases with the distance extrapolated, and this has to be taken into account in any correlation with the terrace heights. The two lower segments (Co 2 and 3) cannot be discussed because the Taplow stage is not represented near Uxbridge. The fourth segment

(171–194 ft. O.D.) gives 158 ft. O.D. at Denham, while the Lynch Hill terrace is at 135 ft. The fifth, the Boyn Hill segment, which is fitted by only one curve, gives 184 ft. O.D. at Denham whereas the terrace is at 165–175 ft. O.D. The curve fitting the segment Co 4 (Lynch Hill) falls to 165 ft. O.D. at Mill End and the gravels at 160–75 ft. O.D. on the west side of the valley are referable to this stage, or to the one above. The gravels on spurs above Rickmansworth on the north bank are of a higher stage than the highest present in the Colne profile (Boyn Hill), as are the gravels at Hansteads.

(v) *Chess and Gade*. The lowermost segments of the Chess and Gade are of Upper Taplow stage, and all stages, including the extra Boyn Hill stage, are represented in the profiles. The fifth stage (Ch and G 3, Boyn Hill) appears to be too high for the gravels at Mill End; the fourth stage (Ch and G 2, Lynch Hill) a little too low. The seventh (Ch and G 5) or Black Park stage refers to the gravels on the Rickmansworth Park, Croxley Green and Watford spurs, in which Chellean implements have been found. The eighth stage gives the height of the Winter Hill stage as 240–250 ft. O.D.—an elevation below that of the gravels on Woodcock Hill which have been assigned to this stage (Hare, 1947, p. 312), and approximately the same as that of the Winter Hill gravels downstream, at Denham.

(vi) *Ver*. From the correlation table (p. 334) the long divided reach V 1 (203–236 ft. O.D.) is of Boyn Hill stage, the next section being of Black Park stage and the upper two presumably of Winter Hill stage. No direct check on the validity of these extrapolations is possible. The fitting of one curve to the section 203–236 ft. O.D. is an error (p. 331), the elevation of 233 ft. O.D. probably being correct for the Black Park stage for which an elevation of 220 ft. O.D. is given at Rickmansworth. The two upper reaches have been allotted to the Winter Hill stage, but there is no means of checking this, and in view of the known history of the Colne in Winter Hill times (Wooldridge, 1938, 1953), it is probable that these segments relate to marginal overflows, or glacial lakes, associated with the Eastern glacier. If so, then strictly speaking they are not Winter Hill segments, although they are related to the Colne or proto-Colne at a time when the Thames was aggrading the various terraces of the Winter Hill stage. These two segments, and the analogous segments of the Harpenden Valley, will be regarded provisionally as of Winter Hill stage and a fuller analysis made at a later date when the upper valleys of the Chiltern streams are examined.

(vii) *Harpenden Valley*. The short section 222–231 ft. O.D. is related to the Colne segment 214–227 ft. O.D. and is of Boyn Hill stage, therefore. This is followed by a long ungraded section equated with the knick (or non-cyclic) reach in the Ver (V 1/2, 236–250 ft. O.D.). On this account the next section (Hp 2) is assigned to the Black Park stage, and all segments above this are provisionally allocated to the Winter Hill stage. As in the case of the Ver, there is no means of making a check, though the height of

244 ft. O.D. for the Black Park is reasonable when compared with 233 ft. O.D. at Hansteads.

The results of the analysis of the streams draining to the Vale of St. Albans are consistent up to, and including, the Black Park stage. However, the analysis, of itself, does not verify the correlation between profiles and terrace stages, for the terrace sequence is incompletely represented and inadequately known. But one can use the completely verified results from the western streams, and by a rule of three the gravels of the Colne Valley can be correlated with those of the Thames. Where this has been done, the scanty means for providing a check has produced no contradiction, at least as far as the Winter Hill stage, but it is at this critical stage in the drainage evolution that the record fails in the eastern streams as well as in the western streams. The eastern streams do show segments of Winter Hill stage, as do the western ones, but their correlation with the terrace elevations, and with each other, is inconsistent. This is to be expected when the complicated drainage history of the Vale of St. Albans is taken into account. Recent work (Wooldridge, 1953) has shown that the Ver and Harpenden streams were blocked by ice and their waters diverted. It is to the levels of the resulting lakes or overflow channels that these streams were graded. This interesting topic cannot be pursued for, strictly speaking, the relevant reaches do not belong to the regular denudational sequence and thus are outside the scope of this paper. The purely empirical and convenient division of the profiles into the systematic and the unsystematic marks a great difference in their respective evolutions. The profiles show quite clearly that the Winter Hill stage was one of intensified morphological change.

(viii) *Apparent Inconsistencies.* The predicted sequence of erosion stages proves to be even more satisfactory than is indicated by a bare statement of identity with the known terrace sequence. At the time when the comparison was first made, Mrs. Sealy's separation of the Taplow stage into an 'upper' and a 'lower' division was unknown. The 'Upper Taplow' Terrace is not recognised as Upper Taplow Terrace in the Colne–Cookham area. On the other hand, an Upper Taplow Terrace is recognised and termed the Lynch Hill Terrace, but it is clearly not to this terrace that the third segments in the various profiles are to be referred. An extra stage is present between the Lynch Hill stage and the present floodplain stage which was not recognised in the Colne–Cookham region (Hare, 1947), but is accounted for in the studies made by Mrs. Sealy further upstream (Sealy, 1951). The actual Taplow Terrace spread at the type locality could be either 'upper' or 'lower', or may be a coalescence of the two. A first impression, gained mainly from the Wye profile, is that the Taplow Terrace is of 'Lower Taplow' stage and that the 'Upper Taplow' is the extra stage. This correlation is adopted in the chronological synthesis given here.

		Hambleden Brook	Wye	Alderbourne	Misbourne	Colne	Chess	Gade	Ver	Harpenden Valley
		Ha 1 & 2	**W 1**	**A 1**	**M 1**	**Co 1**				
FLOODPLAIN	1	98–147 ft.	86–117 ft.	100–112 ft.	110–120 ft.	–113 ft.				
F.P./L.T.	1/2	147–155 ft.	117–122 ft.	112 ft.	120 ft.	113–118 ft.				
		Ha 3	**W 2**	**A 2**	**M 2a**	**Co 2**				
L. TAPLOW	2	155–183 ft.	122–150 ft.	112–126 ft.	120–125 ft.	118–137 ft.				
L.T./U.T.	2/3	183 ft.	150 ft.	126 ft.	125 ft.	137 ft.				
		Ha 4	**W 3**	**A 3**	**M 2b**	**Co 3**	**Ch 1**	**G 1**		
U. TAPLOW	3	183–209 ft.	150–174 ft.	126–141 ft.	125–159 ft.	137–161 ft.	151–156 ft.	152–159 ft.		
U.T./L.H.	3/4	209–239 ft.	174 ft.	141 ft.	159 ft.	161–171 ft.	156–168 ft.	159–169 ft.		
		Ha 5	**W 4**	**A 4**	**M 3**	**Co 4**	**Ch 2**	**G 2**		
LYNCH HILL	4	239–296 ft.	174–194 ft.	141–166 ft.	159–171 ft.	171–194 ft.	168–192 ft.	172–195 ft.		
L.H./B.H.	4/5		194–212 ft.	166–189 ft.	171–188 ft.	194–203 ft.	192 ft.	195 ft.	197–203 ft.	
			W 5	**A 5**	**M 4**	**Co 5**	**Ch 3**	**G 3**	**V 1a**	
	5		212–235 ft.	189–210 ft.	188–207 ft.	203–214 ft.	192–213 ft.	195–212 ft.	203–216 ft.	
BOYN HILL	5/6		235 ft.	210–219 ft.	207–214 ft.	214 ft.	213 ft.	212 ft.	216 ft.	
			W 5b	**A 6**	**M 5**		**Ch 4**	**G 4**	**V 1b**	**Hp 1**
	6		235–261 ft.	219–250 ft.	214–250 ft.	214–227 ft.	213–240 ft.	212–230 ft.	216–236 ft.	222–230 ft.
B.H./B.P.	6/7		261 ft.	250 ft.	250 ft.		240–255 ft.	230 ft.	236–250 ft.	230–253 ft.
			W 6	**A 7**	**M 6**		**Ch 5**	**G 5**	**V 2**	**Hp 2**
BLACK PARK	7		261–290 ft.	250–290 ft.	250–276 ft.		255–296 ft.	230–256 ft.	250–269 ft.	253–274 ft.
B.P./W.H.	7/8		290 ft.	290 ft.	276 ft.		296 ft.	256–264 ft.	269–274 ft.	274 ft.
				A 8	**M 7**		**Ch 6**	**G 6**	**V 3**	**Hp 3**
WINTER HILL	8			290–331 ft.	276–303 ft.		296–338 ft.	264–285 ft.	274–298 ft.	274–309 ft.
									298 ft.	309 ft.
									V 4	**Hp 4**
									298–321 ft.	309–342 ft.
										342–351 ft.
										Hp 5
										351–379 ft.

All heights in the above table are expressed in terms of Ordnance Datum

A further discrepancy, with no corresponding feature within the recognised sequence in the type area, is the subdivision of all the Boyn Hill segments into two apparently independent stages.

These two discrepancies will now be examined, beginning with the latter.

In all the profiles yielding a record of the Boyn Hill stage two segments are found between the Black Park and Lynch Hill stages. The inter-Boyn Hill knick splits the stage as a whole into two almost equal lengths of profile. This makes it difficult to explain the extra stage as a result of a delta-building episode at the commencement of the Lynch Hill stage (see p. 332). Such an explanation requires that a process of this kind occurred at the confluence of both the Wye and the Colne; and to the same extent in either case, for the vertical interval has a range of 10–5 ft., throughout the Chiltern streams, without exception. The suggested explanation to account for the anomalies in the lower courses of the Chess and Gade (p. 328) fares no better, for if the extra stage is a result of grading by the Wye and Colne to a complex knick-section in the Thames, then the knick-section would need to be as long as the graded section. It may be suggested that there is no inherent impossibility in a knick-section lengthening until it equals the length of a cyclic reach and simulates, if it does not actually become, a graded segment. As far as can be judged at present we are dealing with a special instance relating solely to the Boyn Hill stage, and as such it demands a special explanation.

Hare (1947) succeeded in tracing a feature between the Boyn Hill Terrace and the Lynch Hill spread, in the neighbourhood of Stoke Poges. This feature, the Stoke Park Cut, has a thin gravel cover at the western end but otherwise is a bare cut in London Clay. This was regarded as a meander terrace cut during the erosion that terminated the Boyn Hill stage and it is the only morphological feature which could possibly correspond with the extra Boyn Hill stage recorded in the profiles. While it is almost certain that they do correspond, what the feature actually represents is far from clear. The two hypotheses presented to account for the extra stage—a complex knick-section in the Thames, and a meander terrace—are both unsatisfactory.

The stripping of a gravel veneer from the floodplain in advance of the main rejuvenation will account for the required lengthening of the knick-section (v, p. 332). Further, if the stripping is extended laterally from, or by, the river channel it could result in the production of a feature similar to the Stoke Park Cut. But it is most improbable that the primary knick has retreated so successfully in this stage and in no other. This applies to its occurrence as a peculiarity of the Thames profile and its propagation throughout the tributaries in the normal manner. It is even more improbable that, in some way, it is the result of an inherent property of this actual rejuvenation and though not, perhaps, present in the Thames, yet appears without fail in all the tributaries. If this were so, the stripping of gravel by the primary knick has in each case reached approximately half-way and is of similar magnitude. This entails not only a constant gravel thickness throughout the Boyn Hill stage in the Chiltern streams, but also implies that the rates of recession of the primary knick-points are also uniform.

A simple meander terrace will have no corresponding record in the tributary profile. If the main stream degrades so rapidly that the tributaries cannot keep pace with it, then they will become ungraded in relation to the main stream, and there will be an end to the matter, for a knick-point (probably of a convex nature) will be produced in the tributary profile, which, during a further period of stability, will be followed by a graded reach in the profile. But recognition of this necessity for two periods of stability does not solve the problem. The meander terrace either corresponds to the inter-Boyn Hill knick-point, which is unlikely, leaving the lower (extra) stage unaccounted for, or it refers to the lower graded reach, which is more probable, in which case it is no longer a meander terrace for it represents the second period of stability. The mere production of a meander terrace will not result in an extra segment in the tributary profile; it must be accompanied by rejuvenation of the lower reaches. The sweep of the meander must result in a minor hang of the tributary, and for this to happen the gradient of the tributary must attain a certain magnitude (see Hambleden Brook delta, p. 322). This is a possibility in the case of the rivers in question, but will require gradients as steep as, or steeper than, those existing at present.

But the greatest objection to any possible origin in a meander terrace is the position of the inter-Boyn Hill knick. As has been shown, invariably it is sited half-way between the pre-Boyn Hill rejuvenation and the pre-Lynch Hill rejuvenation, a circumstance pointing to an intermediate position, temporally. It can hardly be half-way between the beginning and end of the post-Boyn Hill downcut, as an origin associated with a meander terrace would entail.

The inter-Boyn Hill knick-points, being sharp disruptions of a graded stream profile, cannot be other than the results of rejuvenation. As rejuvenation by a meander terrace cut is ruled out, there remains the possible origins in simple eustatic rejuvenation or perhaps climatic oscillation of the Thames profile. Taking the latter alternative first, the Thames profile may have been modified during the Boyn Hill stage so that the river proceeded to strip off the previously aggraded gravels and so reveal the cut bench. Then, without further aggradation, or before the profile could return to its initial position within the area under consideration, the Thames was rejuvenated (pre-Lynch Hill downcut). Though the morphological features of the area may be adequately explained in this manner the profile feature cannot, for a climatic change of profile is essentially gradual and there is little reason to doubt the capabilities of the Wye and Colne to keep pace with any such slow change of base-level. Thus there would be no break in the profiles to correspond with the change of climate, and any consequent stripping of gravels from the cut bench. There would be no segment in the profiles relating to the Boyn Hill stage, and the sections of the profiles lying between the Black Park and Lynch Hill stages would correspond to the non-cyclic climatic change of base-level.

Therefore extra segments in the profiles relate to a cyclical change of local base-level and are of an equivalent significance to the rest of the profile stages. If the Stoke Park Cut is connected with the extra stage, then it represents a phase of valley widening following the Boyn Hill stage when the tributaries became graded to this level during the period of stability preceding the advent of the Lynch Hill rejuvenation.

When the correlations were first attempted, the knowledge that an Upper Taplow Terrace stage was traceable west of Cookham was not available. The stage falling between the (Lower) Taplow and the Lynch Hill stages in all the profiles was provisionally equated with the Longstock reach which is found in exactly the same position in the relative chronology of the Test profile between the Iver (Upper Taplow or Lynch Hill stage) and the Lower Taplow, by J. F. N. Green (1946). When the results of Mrs. Sealy's researches were made available, the extra stage fell neatly into the Upper Taplow Terrace stage—not the Test stage of the same name which is, so far as can be judged, the equivalent of the Lynch Hill stage. Even so, a minor adjustment had to be made in the case of the profile of the Hambleden Brook (p. 333). This stage was not recognised as such by Hare (1947) in the Colne–Cookham region because the two terrace spreads converge eastwards and the Lower Taplow is poorly preserved.

In the following table the heights of the present terraces (referred to the present floodplain as a datum) are listed for the meridians of Mill End, Bourne End and Slough. For the Slough meridian the elevations are from Hare (1947).

The convergence of the two lower terraces is readily apparent. The elevation at Slough (35 ft. above the Floodplain) renders the terrace spread

Elevations of Terrace stages above the present Floodplain of the Thames

Stage	Mill End	Bourne End	Slough
Boyn Hill I	—	102 ft. } —	110 ft.
Boyn Hill II	—	89 ft.	
Lynch Hill	79 ft.	68 ft.	65 ft.
'Upper Taplow'	65 ft.	45 ft. ?	35 ft.
'Lower Taplow'	44 ft.	30 ft.	

as almost certainly of Upper Taplow stage. The curvature of profile that would be entailed if it were assigned to the Lower Taplow is most improbable in a river of the size of the Thames. The Lynch Hill Terrace also converges on the existing floodplain, but not so steeply. The Boyn Hill stage approximately parallels the present profile of the Thames.

Between Mill End and Bourne End, the two Taplow terraces converge at a rate of 1 ft. in 6000 ft. Assuming that this rate is maintained downstream then the vertical interval falls from 15 ft. at Bourne End to 11 ft. at Maidenhead. At Slough it has dwindled to 7 ft., while in the neighbourhood of Harmondsworth the terraces coalesce. This prediction is liable to error owing to the impossibility of fixing the elevations at Mill End and Bourne End with accuracy, and also because of the arbitrary nature of any longitudinal measurements. The exact course of the Thames in Taplow times is not known, the present calculations being based on the inner edge of the terrace from Taplow eastwards. At Maidenhead, where a vertical interval of 11 ft. is predicted, Hare records that the terrace-remnants on the west bank are 5–10 ft. lower than those on the opposite side of the river, at Taplow. At Slough the actual bluff is visible and the Lower Taplow is preserved as the flat expanse of Lascelles Playing Fields, east of Upton Church (G.R. 981791), while the predicted interval of 7 ft. is approximately correct.

Using the nomenclature adopted by both Mrs. Sealy, and the present author, the Upper Taplow stage is represented by the type Taplow Terrace at the village of Taplow. In the Wye profile it is represented by the segment that refers to a base-level of 131 ft. O.D., at Bourne End. The Lower Taplow stage is found at Lascelles Playing Fields, Slough, and from Maidenhead to Cookham, as a series of remnants rising from 100 ft. O.D. to 110 ft. O.D. at Cookham Station, and it is to this stage that the Wye segment W 2, 122–150 ft. O.D., and the corresponding segments in the other Chiltern streams, refer.

Owing to excessive modification in the form of the profile the Colne cannot supply any information other than that at Uxbridge the two stages are separated by about 11 ft. The two terraces will tend to merge at Harmondsworth and even if they do not intersect for some further distance downstream, any minor bluff will have been obliterated by agricultural operations. The fact that the two segments in the Colne are separated by a knick-point means that the two stages are separated by a period of active downcutting by the main stream and are therefore two separate cyclic stages and not climatic terraces. The production of a knick-point in a tributary profile by mere climatic oscillation of the main stream profile is extremely doubtful. As far as rate of aggradation is concerned, there appears to be no essential difference between that associated with climatic fluctuation and that which built the Thames terraces.

The whole correlation of the profile and terrace sequence is based upon the assumption that the slow rise of base-level attendant upon the aggrading of the Thames terraces is not sufficient to disrupt the tributary profiles and so to produce a knick-point. It is a question of relative rates of profile change. The Chiltern streams are not sufficiently sensitive to record slow changes, such as climatic or eustatic aggradations in the Middle Thames. They have always been capable of regrading sufficiently rapidly to avoid the production of knick-points. The very existence of multicyclic profiles in the Chiltern streams depends entirely on the fact that whereas they are capable of remaining graded to a slowly moving base-level, they fail to do so for a rapid change. If their capabilities in this direction were increased to the extreme at one end of the scale, even the rapid changes of base-level would not be recorded. The stream profile would then be mono-cyclic. At the other extreme, knick-points would appear in tributary profiles upon the slightest change in level of the main stream and the profile would be correspondingly irregular and difficult to analyse. A climatic oscillation in the profile of the Middle Thames would not be sufficiently rapid to be recorded as a knick-point in the tributaries. The Lower Taplow Terrace is not a climatic terrace, therefore, but of the normal cut-and-build variety.

Below Harmondsworth the Lower Taplow stage is represented by any terrace spread at the normal Taplow elevation, unless, owing to a greater concavity of profile, the Upper Taplow stage again becomes the highest in elevation at some point nearer the sea. At present, it would not be advisable to attempt to correlate the denudational sequence at Slough with that of the Lower Thames at Swanscombe, or even with the Test sequence. The question of exact nomenclature is left in abeyance, pending fresh information. If the stages are named or numbered, not from aggradations but from the successive halts in an intermittently falling sea-level to which they refer, then the extra Boyn Hill stage (Stoke Park Cut?) is a separate stage. Also, until the sea-levels are known to which the two Taplow Terrace stages refer, the question of correct designation cannot be settled. Although it appears that the Upper Taplow stage is really the Lower Taplow stage, and *vice versa*, owing to the acute angle of intersection, this is not certain, and furthermore, the downstream curvatures of the stages are entirely unknown.

Thus, the two apparent contradictions in the correlation with the terrace sequence prove not to be so, and therefore the suggested denudational chronology needs no amendment.

6. CONCLUSIONS

The foregoing research not only fills a gap in studies of river profiles round London but also shows that an analysis of longitudinal profiles can provide a reasonably accurate and coherent denudation chronology. The value of the study is not that it enables such a chronology to be deduced, for this has been done before, by other methods, but that it demonstrates how a detailed chronology can be constructed from river profiles alone. Although the method is more sensitive than a morphological approach it is more difficult to apply, for this very reason. A terrace study is easier if the evidence is available, but for this to be so the conditions must be favourable. Such ideal circumstances are present in the region described where the diversion of the Thames has left a magnificent flight of terraces east of Bourne End. Without this diversion the denudation chronology would not be so clear or complete as it is. Yet, even so, the Upper and Lower Taplow terraces were not completely distinguished but were easily recognised in the profiles. Generally an erosional record is more reliable than an aggradational one, for it does not require favourable conditions for its preservation.

The profiles of Chiltern streams are far from ideal for the purpose of profile-analysis. They are steep (in many cases too steep), yet they provide a picture that rivals that derived from terrace studies. In the Chiltern valleys there are no terrace remnants worth mentioning, and transverse profiles are disappointing, yet for the lower reaches a detailed sequence has been obtained. Not every river system has a well-developed terrace sequence, but every river has a longitudinal profile. What the profile method lacks in ease of interpretation it makes up for in width of application.

ACKNOWLEDGMENTS

The author wishes to acknowledge information relating to the Thames terraces kindly given by Mrs. C. E. Sealy, and advice regarding the diagrams provided by Mr. R. Polglaze.

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The Upper Reaches of the Chiltern Valleys

by E. W. H. CULLING

Received 27 January 1955; read 1 April 1955

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ABSTRACT: The upper irregular and unsystematic reaches of the Chiltern valleys are examined. Their present condition is ascribed to the effects of a catastrophic increase in discharge during a glacial epoch connected with the advance of the Eastern Ice Sheet within the area.

Modification of profile form upon the retreat of a profile segment is detected and analysed in the case of the Wye and the Colne. It is given as a general principle that unless a rejuvenation head recedes up a static profile, the terrace profile, the former stream profile and the extrapolated curve of a fitted expression do not coincide. Apart from coincidental compensation extrapolation should not give accurate predictions of relevant base-level.

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1. INTRODUCTION

A PREVIOUS STUDY[2] (Culling, 1956) was concerned with the lower reaches of the Chiltern valleys, but here is described an extension of this survey into the upper reaches of the same valleys. From the lower reaches a coherent chronology was built up, and proved to be consistent, when it was compared with the Thames Terrace sequence by the method of curve extrapolation. But this treatment is restricted to the lower parts of the valley profiles, for at or above the Winter Hill stage the profiles become unsystematic in that no continuous record is apparent. Graded reaches do occur in the upper portions of the profiles, and they can be fitted with logarithmic curves, but unlike those fitted to the lower segments, they do not give reasonable predictions of base-level. Thus, between the upper and lower portions of the various valley profiles examined there are two fundamental differences. The lower portions are complete and continuous in that they yield a record of all the relevant erosion stages and fitted curves give

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[1] Including Discussion on Longitudinal Profiles of the Chiltern Streams, *Proc. Geol. Ass., Lond.*, 67, 1956, 314.

[2] Culling, E. W. H. 1956. Longitudinal Profiles of the Chiltern Streams, *Proc. Geol. Ass., Lond.*, 67, 314–45.

reasonable results upon extrapolation. The upper parts of the profiles, however, record less than the complete sequence of relevant erosion stages, on the one hand, and on the other, more than the cyclic sequence in that ungraded sections are intercalated. Fitted curves give absurd results. Systematic correlation from one profile to another, as carried out on the lower segments, is out of the question. The earlier paper dealt with the more amenable results of a survey of the valley profiles of the Chilterns; this paper is concerned with those sections of the profiles which proved to be incapable of straightforward analysis and interpretation.

2. EVIDENCE FROM THE UPPER GRADED REACHES

The evidence is summarised in the two diagrams (Fig. 1, Fig. 2) of the Colne and Wye river systems. The profiles are shown by continuous lines and the fitted logarithmic curves by discontinuous lines. The upper reaches

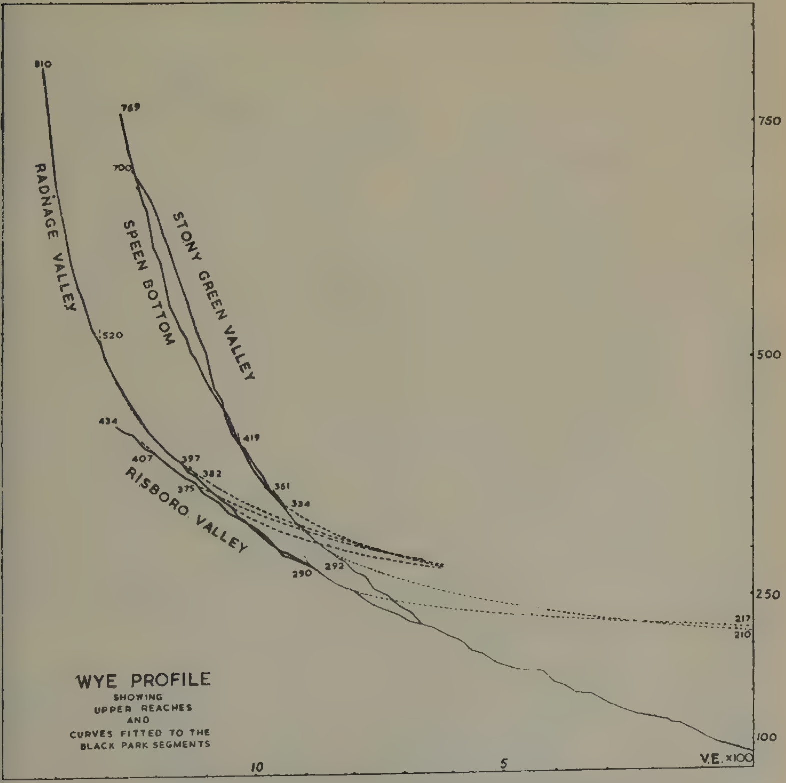


Fig. 1. Longitudinal profiles of the Wye Valley and its tributary valleys

are represented by thickened lines and in the Colne system the curves fitted to the Winter Hill segments are shown. In the Wye profile, the Winter Hill segments fall within the upper reaches, the curves fitted to the Black Park segments being included in the diagram. Significant altitudes on the profiles are given in normal type while figures relating to the fitted curves are in inclined type. These include a system of numbering explained in the earlier paper (p. 319) and indicated in the present text, the height predicted by the curve at the present mouth or at any position specified in the text and the values that determine the fitted curve. Thus, 250/45/9.85 represents $y = 250 - 45 \log (9.85 - x)$ (Green, 1934).

(i) *Wye*. The Wye was taken as an example in the earlier paper, and the upper reaches of its tributary valleys were considered in detail. This detail (Fig. 1) will not be repeated here, but the correlation of the upper reaches, as based upon a direct inspection of the profiles, will be examined further.

Upon extrapolation, both W 6 (261–290 ft. O.D.) and Hu 2 (292–361 ft. O.D.) give a height of about 215 ft. O.D. (210–217 ft. O.D.) at the present confluence of the Wye with the Thames, which is the wrong confluence, of course. For equivalence of stage one would expect an ideal extrapolation to intersect the main profile, or an extrapolation therefrom, at the site of the present tributary confluence. That it does not do this, points either to non-equivalence, which in this case is unlikely, or to a faulty extrapolation. The latter can arise from two causes. The fitting of the curve may be at fault or the profile itself may be so, in which case the extrapolation is erroneous; or the fitting and the profile are accurate, thereby giving a true extrapolation, but not an ideal one in the sense that it does not predict an expected result or correlate satisfactorily with independent morphological evidence. For the accuracy of the plotted profile no positive proof is possible. Reliance has to be placed upon the general accuracy of the method, as outlined in the earlier paper, and the consistency of the results from the lower reaches which are detailed there. But this general consistency is no criterion for any individual instance, for there is always the likelihood of an exception. As the phenomenon of non-ideal extrapolation is as general for the upper reaches as its opposite proved to be for the lower reaches, then in view of the identity of method employed it becomes most improbable that the actual profiles and curves, as plotted, are in error. The error is due to differential warping, to alterations in the position of base-level, or to changes in the form of the profile-segment.

The first two causes are extremely unlikely in the Chilterns. No warping could affect the Hughenden Valley to the required extent without also disturbing the Wye profile. Faulting of adequate intensity and recency would be apparent immediately both in the profile form and in the field. Similarly, there can have been no change in the position of base-level

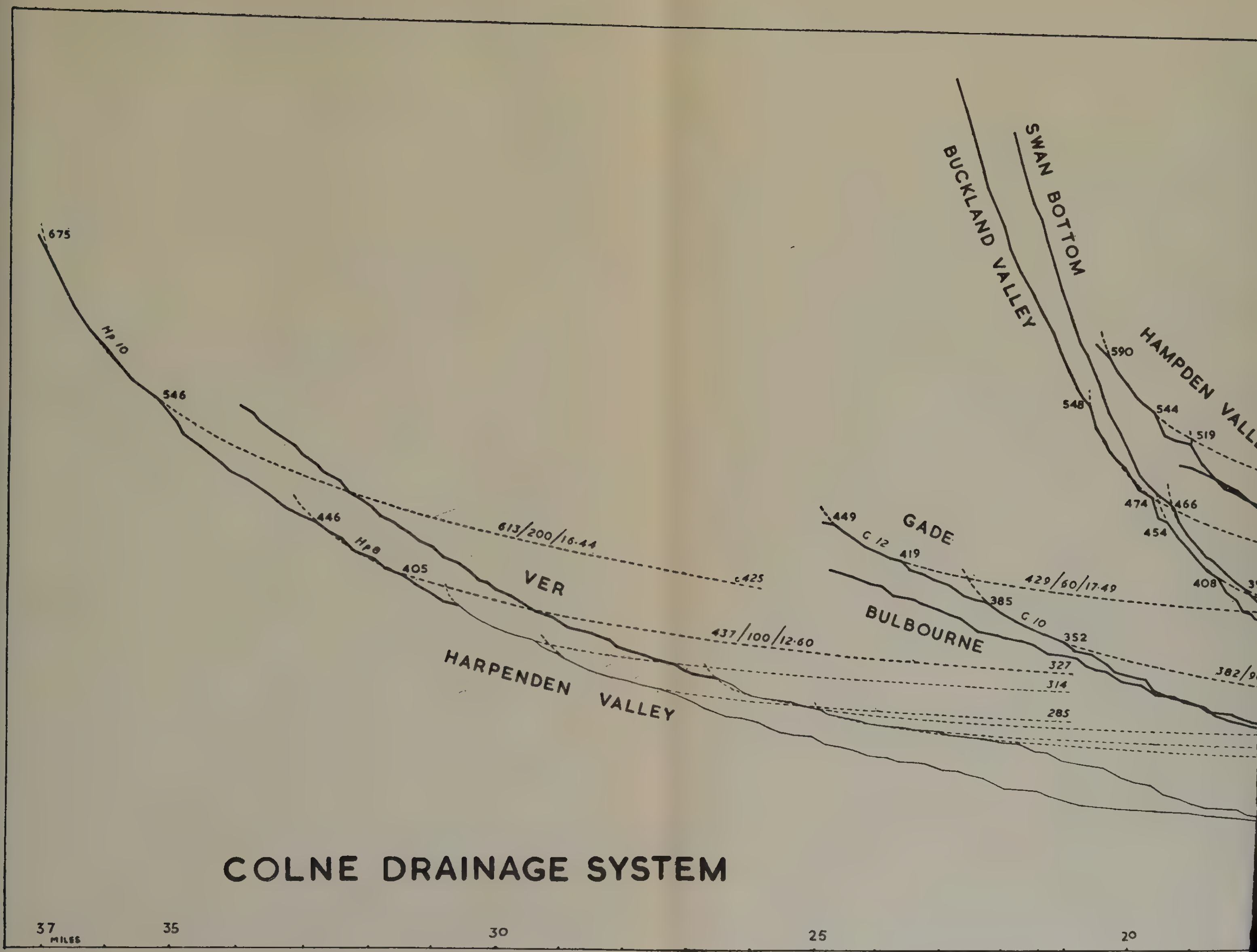
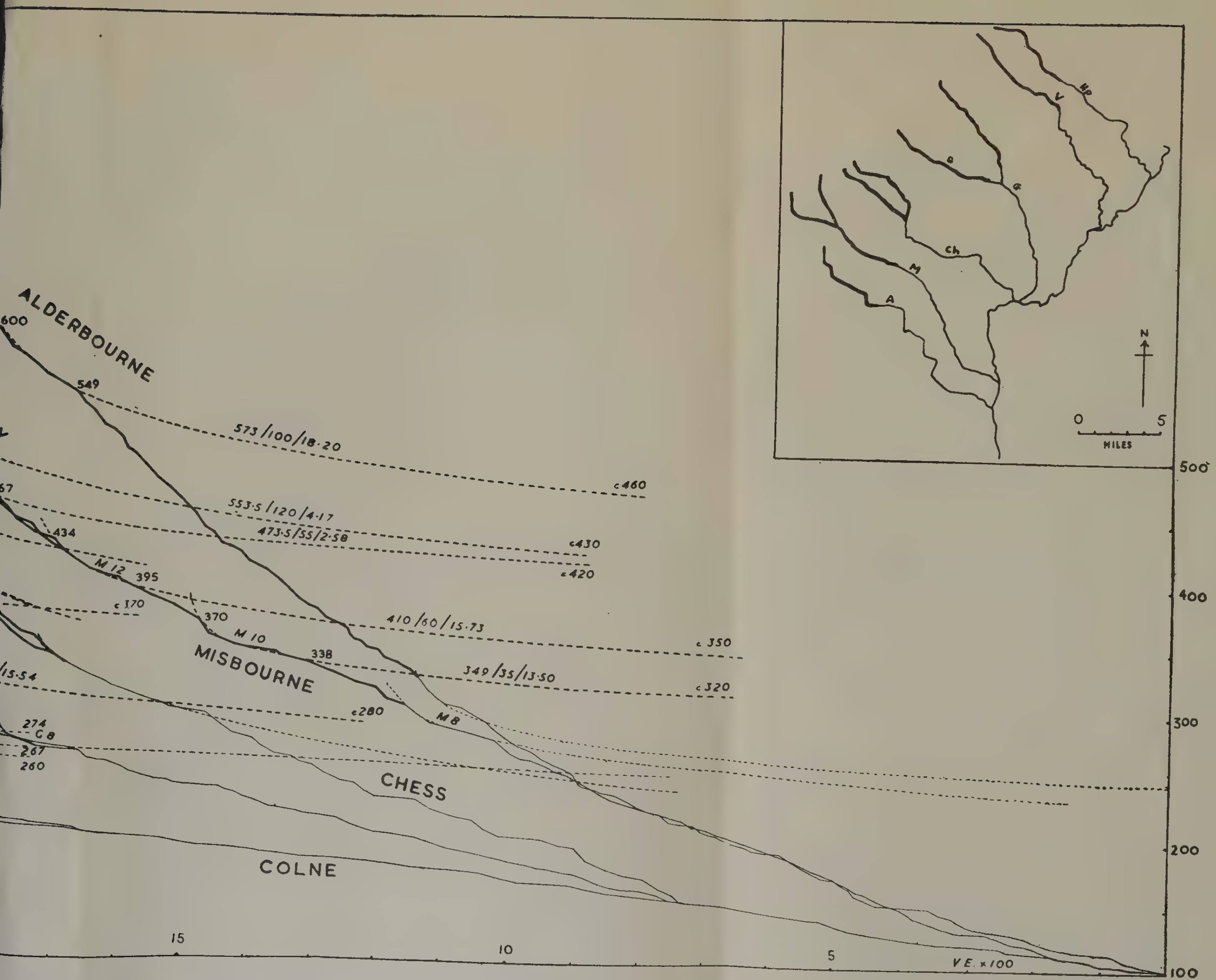


Fig. 2. Longitudinal profiles of the River Colne and its tributaries. The upper reaches of t



tributary valleys are indicated by heavy lines in both inset map and profiles

[*To face p.* 348

greater than from one side of the Wye Valley to the other. But the case of the Wye–Hughenden Valley is an individual instance and as such cannot rank as a positive proof, for the actual individual profile is liable to error, as pointed out above. With the above reservation in mind an extrapolation which, upon comparison with other evidence, fails to give the ideal result is nevertheless most probably a correct extrapolation.

The remaining four reaches of the upper Wye which have been fitted with logarithmic curves are not ideally suited to this procedure. The fit is not very good, the segments are short and for some the curvature is so small that curves with a wide range of parameter will give a tolerable fit. Added to this is the effect of any change of profile form, as outlined above. However, the plotted curves tend to converge towards an elevation of 290–300 ft. O.D. at High Wycombe, and this suggests that they are of comparable stage.

The Callow Down Valley rises from its confluence with the Radnage Valley at 312 ft. O.D. between Bledlow Ridge and the Callow Down–Hearnton Wood Ridge up to the scarp summit at Bledlow Cop. Its main interest is that the asymmetry common to many Chiltern valleys is here well displayed. The gentler western slopes extending down from Bledlow Ridge, show a marked break of slope associated with the deposits mapped as Clay-with-Flints by H.M. Geological Survey (White, 1908). The upper slopes are as steep as the eastern side of the valley but flatten out to form a feature which rises with the valley from about 350 ft. O.D. up to about 500 ft. O.D. at Callow Down. The divide between the Callow Down Valley and the Risborough Valley is breached in three places, and in two instances, between Callow Down and Slough Hill (440–450 ft. O.D.) and between Slough Hill and the Hearnton Wood Ridge (425 ft. O.D.), at a height similar to the valley feature. Similar deposits to the Clay-with-Flints of the Callow Down Valley are found in the Risborough Valley, above Slough, from 400 ft. O.D. up to the watershed (about 440 ft. O.D.). These deposits, and the surfaces on which they rest, appear to be of the same erosion stage. The graded section of the Radnage profile (R 3, 397–520 ft. O.D.) parallels the fall of the erosion feature in the Callow Down Valley and extrapolates to about 350 ft. O.D. at Chawley Farm. Thus, this erosion feature is likely to be of the same stage as the Radnage Valley segment which is one or two stages above the Wye section W 6 (261–290 ft. O.D.) (Black Park stage).

(ii) *Buckinghamshire Valleys.* The Alderbourne, Misbourne and Chess exhibit isolated graded segments in the upper reaches (Fig. 2). If the extrapolations are to be trusted, these segments relate to stages prior to the Winter Hill stage. The two segments in the Misbourne give possible correlations with the Upper and Lower Gravel Trains at Chalfont St. Peter; the segments in the Hampden and Alderbourne valleys relate to

Pebble Gravel stages. The segments in the Upper Chess valleys are too short and steep for the fitted curves to be used for any other purposes than to indicate possible graded reaches.

(iii) *Gade*. Above 352 ft. O.D. the profile has a regular curvature, but owing to the slight concavity, the fitting of a logarithmic curve is more tentative than usual. The next reach is probably cyclic, though now ungraded (385–419 ft. O.D.). The uppermost section (419–449 ft. O.D.) is fitted by a curve extrapolating to about 360 ft. O.D. at King's Langley, an elevation which coincides with that of the Older Drifts. The lower curve yields a height of 275–280 ft. O.D. at Croxley Green, corresponding to the height of the Lower Gravel Train, or possibly to part of the Winter Hill stage. Like the upper Gade, the Bulbourne shows a similar development above the confluence at Two Waters; first a graded reach (Winter Hill), then a series of knick-points, and then three possibly cyclic segments.

Correlation of the segments of the upper Gade, as made above and based upon extrapolated curves, cannot be accepted for the segments in question are well above the confluence. In the case of the Hughenden Valley–Wye confluence it is almost certain that the Black Park segment in the tributary profile has been modified in form since its initiation, whereas the corresponding segment in the main stream has remained relatively stable. This has led to the observed result of the curve fitted to the main stream segment giving a reasonable prediction of base-level and the curve fitted to the tributary segment predicting an identical elevation at the present lower control, which is obviously in error (p. 348). The Gade and the Bulbourne at Two Waters are of approximately the same volume. Unfortunately only the upper Gade provides segments which can be fitted with logarithmic curves and even then the fit is unsatisfactory. Nevertheless, it is extremely unlikely that the indicated correlations of the two segments of the Gade are correct. The volume of the Wye receives little relative increase at the Hughenden Valley junction, whereas at Two Waters the volume of the Gade is approximately doubled. If modification of profile form were related in some way to relative change of stream volume, as revealed by false prediction of base-level upon extrapolation, then it might be possible to predict the observed relationships in the Wye and Gade valleys, according to this hypothesis. Furthermore, the progressive diminution in stream volume from mouth to source provides for a gradual modification of the curvature of any stream segment, and as the rate of modification is dependent upon the relative decrease in volume, to a first approximation, then the rate of profile modification itself increases progressively upstream. Taken as a whole, the Wye decreases in volume upstream, and thus extrapolations become increasingly suspect as one proceeds towards the source. In the main stream the discrepancy becomes apparent only in the uppermost segments, but in reality it is present throughout, whereas at a tributary junction the abrupt decrease in volume intensifies any profile modification and upon extrapolation the discrepancy is immediately apparent. In the Chiltern streams the upper segments are affected by disturbances from other sources that would effectively mask any modification due to volume decrease, but in studies of other streams, e.g. the Dart (Green, 1949), the effect has been noticed already, and will be instanced again later in relation to the Colne profile (p. 357).

(iv) *Ver and Harpenden Valleys.* In studying the lower reaches, the regular segments of the Ver profile below 316 ft. O.D., and of the Harpenden profile below 379 ft. O.D., could not be correlated completely with the general sequence of stages, yet despite their lack of harmony with the general scheme they occur below the point where the continuity of profile record fails. Barrow (1919) first drew attention to the diversion of the Colne tributaries in the Vale of St. Albans by the advance of the Aldenham Lobe and recently they have been traced in detail (Wooldridge, 1953). The anomalous segments of the Ver and Harpenden valleys appear to be related to the stages of this glacial diversion.

In the Ver profile the uppermost graded reach V 4 (298–316 ft. O.D.) gives about 270 ft. O.D. upon extrapolation, assuming that the waters were diverted via Bricket Wood. Near the A 412–405 ft. O.D. junction (G.R. 131037) the gravel reaches 275–280 ft. O.D., and this is approximately the height of the overflow channel. Probably the segment is referable to the waters ponded above the col.

Below St. Albans the Ver has a terrace first seen south of the river, near the gasworks (about 260 ft. O.D.). The Ver segment V 3 (269–298 ft. O.D.) can be fitted by two different curves giving divergent extrapolations, of which the lowermost is to be preferred, upon other evidence (Culling, 1956, p. 328). At Cottonmill the curve gives 265–275 ft. O.D., whereas the terrace is at about 260 ft. O.D. It is probable that terrace and segment refer to the period when the Ver was diverted at Sopwell. The abandoned channel diverges at Sopwell Mill (G.R. 155055) and rises to about 245 ft. O.D. at the A 5–A 405 junction before returning to the Ver Valley at Park Street. The segment regarded as of Black Park stage V 2 (250–269 ft. O.D.) gives a value at Sopwell of 242 ft. O.D. and suggests that the Ver was still diverted at this stage. This interpretation is supported by the presence of a 'gravel feature' on the 'meander core' at about 245 ft. O.D., most readily explained as due to the action of a large stream. Otherwise the valley was abandoned in pre-Black Park stage times, and has subsequently been lowered to give a chance correlation.

The large gently-sloping gravel spread of Handley Page's Aerodrome at Colney Street (245 ft. O.D.) is slightly higher than the extrapolated curve of the Black Park segment, but has a steeper slope and the discrepancy is rectified if the slope of the surface is extended to the present stream channel. This gravel spread, mapped as fluvio-glacial gravel, appears to have been re-worked by the Colne as it shifted southwards across the Vale during the Black Park stage. The lower gravel spreads (about 220 ft. O.D. at Frogmore) appear to be of slip-off gravels, or alternatively, the profile interpretation is at fault. If the latter is the case, then the most probable explanation is that the section of the profile 236–250 ft. O.D. is not a complex knick-section but a non-cyclic graded reach, which is a result of local aggradation, like the similar reach in the Hambleden Brook.

In general, the information given by the lower Harpenden Valley is similar to that provided by the Ver. The lowest graded reach (253–274 ft. O.D.) is of a later date than the glacial diversion since it occupies the valley below Sandridge. Thus, the allocation of this segment to the Black Park stage receives some external support. The next reach (274–309 ft. O.D.), which is at present ungraded, may be connected in some way with the deglaciation of the Harpenden Valley. The three graded reaches, 309–342 ft. O.D., 351–379 ft. O.D., and 405–466 ft. O.D., can be fitted with logarithmic curves which, upon extrapolation, give heights of about 300 ft. O.D., 325 ft. O.D., and 340–350 ft. O.D. respectively, at Nomansland Common. The upper value of 340–350 ft. O.D. is possibly related to the level of the waters that overflowed at the col (about 330–335 ft. O.D.) north of St. Bernards, in which case the two lower graded reaches refer to successive levels in the lowering of the overflow from the lake at Sandridge. The graded reaches of the Ver and Harpenden valleys which occur above the Black Park segments appear to fall within the Winter Hill stage, but not to any recognised terrace stage. They are non-cyclic and related to local levels which are independent of the major eustatic base-levels, but belong to the evolution of the Colne drainage system, for they are related to the diversion that inaugurated the present pattern. The reaches graded to the previous master stream which flowed either eastwards to Hertford, or through the Watford gaps (Wooldridge, 1938), perished during the diversion. The lakes caused by the ice athwart the lower courses of the valleys would extend up the valleys and over a profile graded to the pre-Winter Hill master stream. The consequent aggradation in and above the lakes would erase any record of such times and would also explain the depths of gravel (20 ft. at Harpenden and 30 ft. at Kinsbourne Green (Whitaker, 1922)) in a valley now dry. Only the uppermost graded reach of the Harpenden Valley (546–675 ft. O.D.) can belong to the former drainage system.

Throughout the Chiltern streams the Winter Hill stage marks a sharp break and the Colne system is no exception. The graded reaches occurring above the Winter Hill segments provide no evidence other than that they have been radically altered, though they relate to a drainage system different from the present. The universal hiatus in the profile record conceals a major change of drainage and in those valleys (Ver and Harpenden) where a record of this change might be expected, special circumstances conspire to erase even this evidence.

3. INTERPRETATION OF EVIDENCE

It will be apparent that even if the extrapolations are only approximately correct in their predictions of base-level, considerable intervals of time are represented by varying lengths of profile. The interval between the ostensible Pebble Gravel stage and the later part of the Winter Hill stage is often very short, e.g. in the Harpenden Valley. Also when an attempt is made to correlate the upper graded reaches in a way similar to that adopted in the study of the lower reaches, the absurdity is even more apparent.

In the section on the Wye profile (p. 348) the conclusion was drawn that, in general, extrapolations are true even if they do not provide ideal predictions. Therefore, that the upper graded reaches give suspect results upon extrapolation is not due to the unreliability of the evidence, or to error in the curve fitting, but is the necessary outcome of an actual change in the form of the profile-segments. Furthermore, the abrupt change between the upper and lower portions of the valley profiles suggests a correspondingly abrupt change in the factors influencing the profile form. It is not the expected gradual change of controlling conditions slowly deforming the profile-segment as it recedes, but a sharp disruption occurring at a definite time in the evolution of the profiles.

Objections to this particular conclusion can be foreseen. The change in the nature of the stream profiles may be due not to an event in their evolution but merely to the precise position in the valley profile. The change may be due either to an alteration in the stream regime from the dry or intermittently dry to the perennially wet, or solely to increased gradient. Except in the case of the Wye, the change from a wet to a dry valley does not coincide with the termination of a coherent profile record. In some valleys the flow ceases long before the lower graded reaches terminate—e.g. the Alderbourne—whereas in others, such as the Bulbourne, the stream is still flowing far above the change. It is more than probable that the change from a dry to a wet valley has not always been at its present position in the various profiles, but to assert that the change in the nature of the profile is due to a previous position of the source is to imply that in some streams there has been a migration of the source downstream and in others in the opposite direction. This is totally at variance with the known facts relating to change of water table in Chalk areas. A more compelling argument against the above criticism, and any other based upon position in the profile, is that the change in the nature of the profiles occurs at or immediately above the lowest Winter Hill segment, in all the relevant profiles. Upon any view based upon location, this constancy within the erosion sequence can only be ascribed to coincidence.

In the case of the Hambleden Brook, and perhaps the Wye, it might be suggested that the absence of any record above the Winter Hill stage (Lynch Hill, in the case of the Hambleden Brook) is due to steepening gradients which precluded the development of any systematic profile form. This cannot be so, for graded reaches occur within and above the irregular sections of the upper parts of the profiles. Steepening of gradient does affect the nature of the profile, as in the case of the Hambleden Brook where it has resulted in the systematic record finishing at the Lynch Hill stage, but it is not responsible for the ending of the record at an identical stage in the remainder of the valleys. The gradient at the point of change varies from profile to profile and it is extremely unlikely that the other factors involved in the moulding of the profile form will combine to compensate the divergence in every case.

Excess of gradient contributes to the elimination of knick-points so that even the presence of a cyclic reach in a head valley becomes imperilled. The preservation of a knick-point is dependent upon the relationship obtaining between parallel and headward erosion at the knick-point. Parallel erosion refers to that which takes place at or immediately above the knick-point. If the parallel erosion above the knick-point is anything more than negligible when compared with the headward erosion below, then the break of slope will be gradually eliminated. Lehmann, to whom this observation is due, cites a case where the ratio is 20:1 and where the knick is 200 m. in height (Woodford, 1951). It is a matter of simple arithmetic to see that the knick will be eliminated after a recession of 4 km. Assuming that the knick-point acts as a base-level for the segment above it, then any change in the profile form results in the new profile converging upon the old one towards the knick-point. In the lower reaches of a river the profile often approaches horizontality as it nears the knick-point and so the convergence is extremely acute and the erosion at the knick-point needed for adjustment is extremely small. The knick-point is therefore preserved.

The intersection of the old and the new profile is likely to be less acute the greater the gradient. The increase declivity provides a greater potentiality for change of profile form and in the steep upper reaches, though parallel erosion at the knick may be small, it is no longer negligible and so the break of slope is liable to be eliminated. However, it is not suggested that the mere geometry of the profile provides a sufficient cause for knick-point persistence. A further necessary condition appears to be the preservation of the two bounding inter-knick reaches and this continuity depends upon the non-disturbance of the delicate 'equipoise' (Baulig, 1950) of a graded stream segment. The functioning of a knick-point as a base-level control is due to its being the least variable point in the stream segment. This is a result of the segment behaving as an integrated unit upon recession in which all processes tending to modify the profile attenuate towards the knick-point. The relative stability of knick-point elevation is dependent upon the segment above being in a graded condition. It will be readily apparent that the functioning of a receding knick-point as a base-level control is of vital importance to the concept of logarithmic extrapolation.

For our immediate purpose we may surmise that the disruption of the graded condition consequent upon a catastrophic increase in stream volume will terminate the rôle of the knick-point as a base-level, thereby enabling parallel erosion to proceed. Under such conditions knick-points will not persist, as the excessive volume of water will tend to override the breaks of slope and merge any cyclic reaches, striving to attain a new equilibrium adjusted to the new conditions. Such conditions will be provided when a dam bursts or glacial overflow or outwash takes place.

The change in the nature of the profile at the Winter Hill stage was definitely an event in time and is not a reflection of present or past topographical or hydrological conditions. In looking for such an event the factor of climatic change appears the most obvious. In the Vale of St. Albans the Winter Hill stage, and the time immediately prior to this, was one of critical drainage changes. During this period the Chilterns experienced a periglacial, if not a completely glacial climate. Wooldridge (1938) has traced the effects of the advancing Aldenham lobe of the eastern glacier, and, more recently, the marginal drainage features of this lobe (1953). Hawkins (1923) suggested that ice-lobes advanced down the Risborough and Bulbourne valleys and also into the Wendover Gap. Barrow (1915) was convinced that ice had moved eastwards across the Chiltern Plateau and overthrust the gravels at Cowcroft. Whether the more extreme positions are fully tenable or not, there is no doubt that during such a period of climatic deterioration the modification of the stream profiles may have been of such severity that any hopes of ideal extrapolation are entirely misplaced.

It has been pointed out that a great increase in volume of water passing along a graded reach, such as would accompany a glacial overflow, will tend to disturb the equilibrium of the reach and promote parallel erosion at the knick-points, thereby leading to their elimination. Some of the Chiltern streams—especially the Ver—appear to have been subject to this process. The overflow waters from ice in the Vale of Aylesbury would be heavily laden and any diminution of volume would result in wholesale aggradation which would radically alter any graded profile-segments if it did not overwhelm the whole valley with gravel deposits. Upon climatic amelioration the streams had to remove the deposits and reshape the profile, often as if from the beginning. In some cases old graded reaches, not entirely obliterated, were reshaped and now exist as the upper graded reaches. In other cases, perhaps, new graded reaches were developed, with minor barriers in the valley deposits acting as local base-levels. Most of the deposits have been removed, but the graded reaches remain. Whether the present upper graded reaches are old graded reaches which have been remoulded, or are entirely new segments or reaches that have suffered only deformation, cannot be settled, but there can be no doubt that any logarithmic curve which is fitted to them will give ideal results only by coincidence.

In the Risborough Valley, near Saunderton, the cover of loam-with-flints may be a remnant of the fluvio-glacial deposits, persisting because of the weakness of erosion at the watershed. Similarly in the Callow Down Valley, where the stream, in entrenching on one side of the valley, has left the deposits on a valley bench. The upper Chess and Wye head valleys, the Turville (Hambleden Brook) Valley, the Alderbourne and the Hampden and Harpenden valleys do not breach the scarp and no overflow waters could have cascaded down their slopes. Therefore they have suffered less from the periglacial and glacial conditions than have those streams which, in rising to wind gaps, provided an overflow for the waters in the Vale of Aylesbury. The reason why graded reaches are not found in most of the valleys that do not head in wind gaps is that their extreme steepness has resulted in the elimination of knick-points. The Stony Dean Valley, Speen Bottom and the Turville Valley would not retain multi-cyclic characteristics even under completely normal climatic conditions. Where graded reaches do occur, as in the Radnage Valley, Swan Bottom and the Buckland Valley, they have been so affected by periglacial deformation of profile form that extrapolation gives unreasonable or demonstrably absurd results.

The graded reach in the uppermost Alderbourne, at Prestwood, may perhaps be explained in terms of a form of glacial protection. On the plateau the ice filled the shallow valley of the Alderbourne and remained relatively static while the melt waters obliterated any traces of a cyclic nature from the lower parts of the valley. Thus the upper graded reach has escaped disruption. Probably the same applies to the uppermost reaches of the Harpenden Valley and to the Hampden Valley.

Thus, it may be concluded that the inconsistent nature of the extrapolations from the upper graded reaches of the Chiltern streams can be adequately explained by the effects of climatic deterioration. In some cases this has meant a catastrophic change of stream regime and the consequent erasure of any multi-cyclic characters. In other more sheltered cases the climatic change produced deformation rather than disruption. But this deformation is the result of normal erosional processes of unusual intensity. Where the influence is intense the result is obvious but one would also expect the more moderate action of normal erosion to produce a subtler but nevertheless recognisable change in the profile form.

The Lower Colne Profile. Although the Colne is properly regarded as one of the lower graded reaches, upon extrapolation fitted logarithmic curves give predictions with a considerable positive error in every instance. There are several possible reasons for this as, for example, the unavoidable inaccuracies in measuring distances along the Colne owing to its braided nature or the lengthening of the profile resulting from such a regime. But the most important influence of all arises in connection with abnormally low values of the parameters of the fitted curves. In the section relating to the upper graded reaches the conclusion was reached that there is no reason to doubt the accuracy of the profile in general and that despite the failure of any extrapolation to provide an ideal result, nevertheless it is likely to be a true one (p. 348). This applies with equal force to the Colne profile, as does the further conclusion that the discrepancy is primarily due to modification of the profile form. According to Green (1936) the parameter value is directly related to the stream volume, though the relation can be by no means a simple one, nor does it act in isolation. That the Colne has suffered diminution of volume there can be no doubt. Besides citing its braided nature, its many dry tributary valleys and the abnormal size of the valley, one can appeal to its past history as a glacial overflow. The curvature of the profile-segments has been changed by meandering and braiding, and also by aggradation. The fact that, as a rule, parametral values increase upstream (also noted by Green, 1936) implies that curvature of profile is not solely dependent upon volume. It is only where volume change becomes predominant, as in the uppermost reaches, at a tributary confluence, or where for some reason the volume of a stream has been seriously depleted throughout, that the profile curvature is affected by this factor. In the first case the parameters increase in value upstream and then decrease relatively in the uppermost reaches; in the second there is an abrupt change in value; in the third the value will be decreased absolutely throughout the profile though the tendency to increase in value upstream will still remain. The Colne falls into the third category.

By applying the full expression of O. T. Jones (1924), the tendency for extrapolation to give high values can be counteracted. The segment (118–137 ft. O.D.) is well fitted by the expression

$$y = 129 - 21 \log (5.58 - x),$$

which, upon extrapolation, yields 113.3 ft. O.D. at Uxbridge Moor, where the Alderbourne profile gives 109 ft. O.D.; and upon a further prolongation of five miles to Longford Bridge (G.R. 050772) the value predicted is 107.5 ft. O.D., whereas thereabouts the Taplow Terrace spread to which the segment refers is at about 95 ft. O.D. By adding a linear coefficient, the expression

$$y = 129 - 21 \log (5.58 - x) - 0.707 (5.58 - x)$$

is arrived at and this, while still giving a good fit and providing an extrapolated curve that passes Uxbridge Moor at 109.5 ft. O.D., still gives too high an altitude at Longford, i.e. 100.1 ft. O.D. A similar result is obtained from the Upper Taplow segment (137–161 ft. O.D.). The simple expression used is

$$y = 161.5 - 32 \log (9.91 - x),$$

but in order that the extrapolated curve should pass Uxbridge Moor at 121 ft. O.D. (altitude given by the Alderbourne profile), the expression employed is

$$y = 161.5 - 25 \log (9.91 - x) - 1.59 (9.91 - x).$$

This curve predicts a height of 109.9 ft. O.D. at Longford, which is again too high, for the two Taplow terraces are at about the same elevation in the area.

It is possible that the height given by the curves fitted to the Alderbourne are in error, thereby explaining the high values at Longford. Yet the curves are good fits and the distance extrapolated is small—in one case, less than the length of the segment. It is unfortunate that no remnant of the Taplow Terrace has been left at Uxbridge but the error cannot be great. Assuming that the heights given by the Alderbourne profile are correct, then a further explanation is required for the discrepancies at Longford. This is found in a change of profile form. As the two segments have retreated upstream, the Colne profile has been regraded to comply with changing conditions and this has entailed a readjustment of the profile which has taken the form of a decrease in parameter value and a consequent positive error upon extrapolation. Upon retreat, this change of profile form means that the terrace level marking the former floodplain at successive loci of the point of rejuvenation is less concave than the extrapolation of the fitted expression which provides a correct prediction of base-level. There is, however, no reason to regard the Colne as unique in that its profile, or the individual profile-segments, are mobile. It is different in that the rate of profile change is greater than usual. All graded profiles are 'in motion' and the changes in profile form, though the product of a complex interplay of various factors, can be classified in terms of increases or decreases of parameter value, the continued predominance of one class eventually leading to a recognisably discrepant prediction upon extrapolation. An ideal prediction demands their 'balance'—not their equality. A profile-segment which retreats with no change of curvature will not give an ideal extrapolation. Mobility of profile is essential for an ideal extrapolation unless the profile above the retreating rejuvenation is static.

The interpretation of the next segment of the Colne becomes more difficult. This is to be expected, but the change of profile has been too intense to be explained entirely by a gradual decrease in parameter value. The segment is that of the Lynch Hill stage which extends as a long flat reach from Oxhey Hall (171 ft. O.D.) up to Munden Farm (194 ft. O.D.). The fitted logarithmic curve

$$y = 198 - 33 \log (16.53 - x)$$

is not a very good fit and although the extrapolated curve is only two feet above the height given by the Gade profile at Rickmansworth, at Denham the height predicted is 159.9 ft. O.D. compared with the Lynch Hill Terrace spread at 130–135 ft. O.D., and the extrapolated value from the Alderbourne profile of 131 ft. O.D. At Richings Park, where the Lynch Hill Terrace surface is at 115–125 ft. O.D., the extrapolated curve indicates an elevation of 156.2 ft. O.D. Owing to the large discrepancy at Denham (25–30 ft.) it proves impossible to fit an expression of the O. T. Jones type so that 135 ft. O.D. is predicted at Denham without serious divergence from the actual stream profile. Whereas the two lower reaches give rather inconclusive indications that the profiles of the stream segments have changed and falsified any results arrived at by extrapolated curves, the Lynch Hill segment cannot have attained its present form without great modification of profile. This modification appears to differ from that affecting the lower segments in kind as well as in degree.

The Colne profile reveals a slight 'convexity' at Rickmansworth and this increased gradient below the junctions of the Chess and Gade may be due to the load contributed by the tributaries, as in the classic instance of the Missouri–Platte confluence (Mackin, 1948). At a former time the small Hambleden Brook brought down to the Thames a load sufficient to build a delta across the floodplain (Culling, 1956, p. 322). If the load contributed to the Colne by the Chess and Gade was much larger at one time, then these streams would be able to build a delta out across the floodplain of the main stream. The increased load would necessitate an increased gradient in the Colne below the junction, and a decrease of gradient above the junction owing to the hindrance to flow. This hypothesis of increased gradient at a former period is capable of partial verification. At first sight the marked change in gradient at the Croxley Green knick-section appears to supply such a verification (4.85 ft. per mile above; 14.9 ft. per mile below; two knick-points in each section). But the knick-section is sited above the confluences with the Chess and Gade and though the slight 'convexity' of profile at Rickmansworth can be adequately explained by the increased load at the confluences, the marked difference in gradient between the Lynch Hill segment and the Upper Taplow segment cannot be so explained. What is required is the demonstration of a similar change in gradient between the Lynch Hill segment when it was below the junction, as compared with its present gradient, and also, if the change is due to a greater load contributed at a former period, an explanation as to why the change of gradient at Croxley Green has persisted.

An idea of the change in gradient may be demonstrated by tracing the former profile of the Lynch Hill segment. It is possible to do this under certain conditions, but for reasons which will be mentioned below, only an approximate indication can be given. A logarithmic curve of the type employed by J. F. N. Green (1934) can be drawn through any three points which are so related to a datum that the perpendicular distance decreases in passing from the first to the third, and these three points suffice to determine the parameter of the curve. When the curve is fitted to a stream profile, the datum is horizontal. Further, given three altitudes on a former river profile it is possible to find a logarithmic curve which fitted the profile at one particular instant in the past. Difficulties arise when it is realised that such a curve does not represent a terrace profile left upon the retreat of the stream segment. In most cases the discrepancy will be small, but it is hardly likely to be negligible. Where the discrepancy will be great is in the upper portions of any reconstructed profile, for this section of the profile will be degraded before being finally left as a terrace. Below the point on the curve where the segment terminated at the time to which the reconstruction refers, the curve is, in effect, a normal extrapolated curve and is subject to the usual sources of error. If the form of the retreating profile-segment changes, then the extrapolated curve will not describe the terrace profile and cannot be reconstructed properly from portions of it. However, meanwhile the assumption is made that the discrepancy from this source is negligible in comparison with that due to other sources of error. If, when the reconstruction has been made, the difference in gradient is so marked that any error of this origin will fail to make any material difference, then the use of the assumption will be justified, in this instance.

Theoretically it may be possible to reconstruct the profile from any three points, but in practice this is not so. Owing to the impossibility of determining the exact elevations of the terrace remnants, further qualifications are required. However, for reasons already outlined above, precise accuracy is not necessary, but the inevitable errors involved in determining terrace elevations are liable to amplification unless the points selected are suitably spaced, both horizontally and vertically, and it is essential in rivers of the size of the Colne that one of the points should be sited so that, on the fitted curve, it is approximately where $(p - x)$ is equal to unity. The smaller the value of $(p - x)$, the greater the rate of change, so by taking a point where $(p - x)$ is less than unity a sensitive indication of parameter magnitude is ensured. In the Chiltern streams the point where $(p - x)$ is unity normally falls within the actual segment, so to take a terrace elevation is to select a point where $(p - x)$ is relatively large and the rate of change correspondingly small. This explains why it is usually impracticable to employ terrace elevations alone to determine logarithmic curves and then extrapolate upstream until the profile is intersected.

However, in striving for sensitivity a further source of error appears. If the point where $(p - x) = 1$ is found to fall within the segment, then, apart from a chance siting at or immediately above the actual knick-point, it is liable to considerable lowering before being left as a terrace. Taking the point where $(p - x) = 1$ as a convenient though arbitrary compromise, to diverge in one direction involves loss of sensitivity, while to diverge in the other direction ends in contradiction, for it entails the employment of a point of which no trace can possibly be left in the landscape. The only point on an actual stream profile which is assured of a place in the landscape is the one immediately above the head of rejuvenation, and the terrace profile is made up of an infinite succession of such points.

If the stream segment is modified by parallel erosion, the retreating knick-point does not traverse the curve of a profile but one that reflects the relationship between the rate of parallel erosion and the rate of knick recession. In an ideal case the knick-point would commence to retreat from the mouth up an almost horizontal profile. In fact, upstream the retreating profile-segment gradually steepens, parallel erosion increases correspondingly, and at an increasing rate. The resulting terrace profile is less concave than the stream profile and as it approaches the mouth it also approaches the horizontal asymptotically. The properties of the curve described are satisfied by a logarithmic expression, but, apart from coincidence, this does not provide a general explanation for the success of logarithmic extrapolation, for it represents an ideal case. Normally the rates of both types of erosion vary irregularly. Nevertheless it is possible for lack of refinement in field survey to make up for divergence from the coincidental ideal.

The theoretical difficulties associated with any reconstruction of past stream profiles can be summarised in one general conclusion. Apart from special cases, the profile-segment is liable to modification of profile form upon retreat, and unless this modification can be estimated and its effects accounted for, not only the hypothetical reconstruction of profiles by extrapolation from terrace and base-levels, but also the complementary prediction of base-levels by extrapolation from stream profiles, becomes liable to error.

In the case under consideration the practical requirements are reasonably well fulfilled. Two terrace heights are available at Richings Park and Denham, separated by just under four miles and by a 10 ft. vertical interval. Assuming a similar length to that applying at present, the reconstructed segment ends above Denham and so the two terrace heights were in fact terrace heights and were not subject to any further lowering as they would be if they were still parts of the floodplain. The extrapolated value given by the Chess and the Gade for the Lynch Hill stage is the third necessary point. When the three points are connected by a logarithmic curve it falls near the point where $(p - x) = 1$. In the case of both terrace surfaces the upper value was taken, i.e. 125 ft. at Richings Park and 135 ft. at Denham. The height taken at Croxley Green is 165 ft. From these three points the logarithmic curve

$$y = 208 - 70 \log (12.66 - x)$$

can be determined.

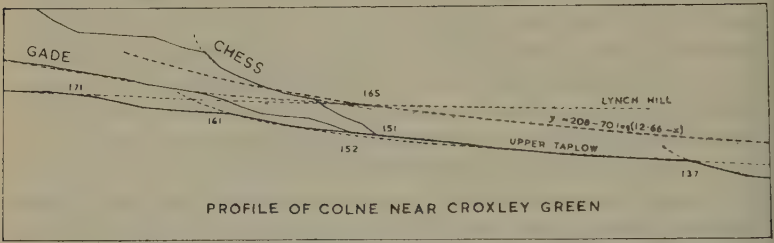


Fig. 3. Longitudinal profiles of the rivers Colne, Chess and Gade, together with a reconstruction of a former profile of the Colne

This curve is shown on the illustration of the Colne profile (Fig. 3) and represents the Lynch Hill segment when the Lynch Hill/Boyn Hill (second stage) knick-section, now at Hansteads, was in the neighbourhood of Oxhey. This is not entirely correct, for apart from the errors involved in using inexact terrace elevations there are other errors. Just as the two Taplow segments appear to have suffered deformation, it is probable that the Lynch Hill segment has suffered likewise, in which case the curve which has been drawn is too steep. On the other hand, the extrapolated value at Croxley Green, which can be regarded as substantially correct on account of the short distances involved in extrapolation, represents the height of the Colne floodplain immediately prior to the rejuvenation by the Lynch Hill/Upper Taplow knick-section. Therefore it is lower than the height of the Lynch Hill floodplain when the latter was in the position indicated in the illustration. Thus on this account the gradient of the profile is not steep enough, and the two errors will tend to cancel out. If anything, the latter error is the more certain if it is not the larger, for should the flattening of the profile be due to depletion of volume then this depletion may not have occurred when the Lynch Hill segment was near Rickmansworth. Therefore the curve shown describes a profile which is of a gentler overall gradient and of a slightly larger parameter than that of the actual Lynch Hill segment. The probable errors tend to decrease the contrast in gradient between the present Lynch Hill segment and its former condition, yet the difference is readily apparent. The assumption made earlier on that the terrace heights could be used to determine the former profile is now seen to be justified, for upon including an estimate of the error due to profile deformation we have concluded that this error is more than counterbalanced. Therefore the Lynch Hill segment has been radically deformed in its passage past Croxley Green and this is in perfect accord with the hypothesis of excess load derived from the Chess and Gade. However, it appears to be more than a simple deformation.

When the Lynch Hill segment was passing Croxley Green the Chess and Gade contributed a load such that the Colne was obliged to reform and steepen its profile to accommodate the increased burden, eventually entailing the adoption of a sigmoid form for this profile in an attempt to retain stability. The indications are, however, that the load so contributed finally became so great that the Colne could no longer transport the increased burden. The upper part of the Lynch Hill segment was ponded back, thereby effectively splitting the segment into two. The lower section was destroyed by the recession of the Upper Taplow/Lynch Hill knick-section, while the upper part remains, and is virtually related to the former delta. The disruption of the graded condition broke the essential continuity with the result that the Lynch Hill segment (171–194 ft. O.D.) is non-cyclic, having no relation to the Thames Terrace stage.

The change of gradient at Croxley Green suggests heavily laden streams, possibly owing this state to periglacial conditions at a period when the Lynch Hill segment was passing that point. This time is most likely to be the latter period of the Lower Taplow or of the Early Floodplain stage. During the interval between the Lower Taplow stage and the present Floodplain stage, complicated glacial eustatic changes affected the Lower Thames but the direct influence of these changes never reached the Middle Thames for the rejuvenations have been overwhelmed and left as buried channels. However, the indirect effects of the changes in climatic conditions did have an extensive influence and in such special cases as the Colne and Hambleden Brook they can be studied.

The Colne is entirely of post-Winter Hill date and has thus escaped the fate of the upper reaches of its tributaries. However, it has suffered from a later period of climatic deterioration, which does not appear to have effected the tributaries. Although peculiar circumstances continued to deform the Colne profile at Croxley Green it is surprising to find no trace at all of such deformation in the tributaries. Also it is surprising to find that the radical modification of the profile is limited to the confluence at Croxley Green. Perhaps the Ver built a delta at this time, but no recognisable effect can be attributed to the Alderbourne or Misbourne, unless the constriction of the Colne Valley above Rickmansworth, and the close proximity of two tributary confluences, made the task of damming the river both easier and more probable. Owing to a steady depletion of volume, the Colne has also suffered a gradual deformation of its constituent profile-segments. Again this is a peculiarity of the Colne, but only one of magnitude. Upon recession a profile-segment must modify its form, with consequent repercussions upon the validity of logarithmic extrapolation. One would expect this aspect of the Colne profile to be repeated, though not so obviously, in the tributary profiles. Yet in the study of the lower reaches of the tributaries no such influence is recognisable, and thus one would be fully justified in concluding that logarithmic extrapolation gives reasonable predictions of base-level. However, this is totally at variance with theoretical considerations (Miller, 1939), and with the findings of the present study.

It is not that the two lower profile-segments of the Colne are special cases; they exemplify the general rule that logarithmic extrapolation does not give a true evaluation of base-level. Rather, the consistent results from the lower reaches of the Chiltern streams, other than the Colne, are due to special circumstances. The general rule is for mobility of profile, in which there is every gradation from complete disruption, as in the Lynch Hill segment of the Colne, through various degrees of mobility as indicated by the imperfect nature of extrapolations in the Taplow stage segments, to the other extreme, where the profile remains almost steady. At first sight this latter state of affairs appears to be present in the majority of the lower segments of the Chiltern streams. Probably it is due to a delicate balance between the various controlling factors tending to deform the profile in contrary directions. Only where one factor becomes predominant, as in the Colne, is this balance upset to any great extent.

4. CONCLUSIONS

(i) In general there is no reason to suspect either the accuracy of the stream profiles or of the fitting of the curves. If upon extrapolation, the fitted logarithmic curve does not give a reliable indication of relevant base-level, then, so far as the Chiltern streams are concerned, the discrepancy is due to a change in the form of the profile-segment.

(ii) The upper graded reaches of the Chiltern streams have been deformed by fluvio-glacial action consequent upon the advance of the Eastern Ice Sheet in Winter Hill times. The deformation varies in intensity, partly depending upon whether or not the stream valley functioned as an overflow route.

(iii) The Lynch Hill segment of the Colne profile has been completely disrupted during a later phase of periglacial conditions which occurred in the period between the Lower Taplow stage and the present Floodplain stage.

(iv) The profile-segments of the Colne have suffered deformation which is correlated with, and most probably caused by, relative depletion of volume. The deformation is accentuated in the case of the Colne, but if the diagnosis is correct, then all profile-segments are liable to deformation.

(v) Given that the profile-segments are modified upon retreat, then the terrace profile (loci of the retreating knick-point) does not represent a former stream profile and the extrapolated curve of a fitted expression does not describe either a former stream profile or the terrace profile.

(vi) For the terrace profile, the extrapolated curve and the former stream profile to coincide, the knick-point must recede up a static profile.

(vii) The mobility of any one profile-segment falls within a continuous range between the two extremes of complete disruption and immobility. Thus, the general conclusion is that logarithmic extrapolation gives faulty predictions of base-level. Where reasonable predictions are obtained with the aid of this method, we are dealing with special cases.

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DISCUSSION

DR. J. F. KIRKALDY congratulated Mr. Culling on the results of his study of the Chiltern valleys. Such an investigation had long been needed. The agreement between the different valleys was very striking. The speaker was not convinced that sufficient attention has been paid to the effects of solution in the upper ungraded portions of the valleys, whilst he would have been happier if the extrapolation of such small fragments of graded reaches had been related to terrace fragments.

MR. K. M. CLAYTON said that although the author has suggested the knick-points in the upper reaches of the valleys may have been eliminated by increased stream flow, an alternative explanation seems possible. When the ice-sheet reached the Vale of St.

Albans the Chiltern area would have experienced a considerable amount of mass movement on the valley sides and floors, particularly as a result of solifluction. This sludging of material would give an irregular valley profile which would survive in the upper parts of the valleys, at present unaffected by the later rejuvenations.

DR. G. DURY said that, in connection with the extrapolation of profiles, he would like to invite Mr. Culling's comments on the account published by Professor Miller some years ago where it was shown that two elaborate equations, each giving a perfect fit for a partial profile, indicated, on extrapolation, base-levels differing by fifty feet. At the same time, the speaker was impressed by the fact that Mr. Culling's extrapolations, as suggested on this occasion, did in fact give acceptable results, and he would like to add his congratulations to those of other speakers on the bulky array of instrumental data which Mr. Culling had collected.

The increase of rainfall which was mentioned would be better styled an increase of run-off. It is improbable that the increase was associated only with the nearby presence of Eastern Ice; for, wherever that ice-sheet be placed in the Pleistocene sequence, there is widespread evidence of river discharges much higher than those of the present day, not only when Eastern Ice stood in the London Basin but also at other, and later, times. Indeed, the last episode of very great river discharges can be brought at least as late as immediately pre-Boreal times; that is, down to the end of the Pleistocene, as has been proved by the study of filled channels in meandering valleys, while the work of Jennings on the Norfolk Broads shows that discharges considerably greater than those of the present day also obtained both in the Atlantic and in the Sub-Atlantic climatic phases. It must follow that not only the upper parts of the Chiltern profiles, but also the lower parts, were subjected to the influence of streams more voluminous than the present ones.

MR. S. A. HARRIS said that one of the most striking features of the Chalk-lands of the south-east of England was the widespread occurrence of the U-shaped cross-section in dip-slope valleys, and the outstandingly rounded form of the hills. These are all the more remarkable when they are compared with a Chalk-land region outside the area of possible glacial action.

Such an area is found in Palestine and Transjordan, near the Rift Valley (at present part of the Kingdom of Jordan). There, at and around present sea-level, soft Senonian Chalk (softer than most of the English Chalk formation) is under erosion in a Mediterranean-type climate. The total rainfall is about the same as it is in South-East England, but only falls during the winter months. At the same time, there is little vegetation to impede surface wash, while the high summer temperatures cause mechanical disintegration and transport of the surface material. Thus, it might be expected that the landforms found in this case would be similar to those resulting from the operation of a higher rainfall on a frozen surface. The valleys actually found around the Rift Valley are primarily V-shaped, while in the more mature ones, a narrow, flat floodplain occurs between the V-shaped valley sides. No U-shaped valleys are found. On the other hand, examples of V-shaped valleys do occasionally occur in the Chalk-lands of South-East England, e.g. the Devil's Dyke and Coombe Bottom (G.R. 4965, 2176, near Dunstable).

Turning our attention to the erosion forms found on recently uplifted scarplands, examples in desert regions show maximum downcutting by the scarp-face streams but relatively little downcutting on the dip-slopes, especially in the upper courses of the streams. This is in marked contrast to the exceptional downcutting demonstrated by Mr. Culling in the upper courses of the Chiltern streams.

During the maximum extension of the ice into the Vale of St. Albans, at the time of the Lowestoft Glaciation, it is quite conceivable that a local ice-cap may have existed near the higher parts of the Chilterns. In mountain glaciation, the maximum erosion takes place where the ice is thickest, i.e. near or at its source, and progressively diminishes with decrease in thickness towards the margins. Thus if a local ice-cap was formed, overdeepening of the upper parts of the dip-slope valleys would be expected. Furthermore, upon the melting of the ice at the end of the cold period, large volumes of water would be produced which might be expected to cause a well-defined erosion platform and knick-point in the streams unless there was a rapid change in base-level occurring concurrently. This knick-point should be traceable in all the streams in the area, and thereafter every drop in base-level followed by a period of standstill should be represented by similar knick-points. On the other hand, all the earlier knick-points originally present in the glaciated area would have been destroyed, of course, and an uneven surface would be left.

This is exactly what Mr. Culling has found in his present survey. In fact, the highest knick-point represented in the streams would seem to be that corresponding to the Winter Hill Terrace, which is generally accepted as coincident with what is now called the Lowestoft Glaciation.

The speaker therefore asked the author whether he considered that a possible cause of the Chiltern river-profiles which he had described could reasonably be a local glaciation of this kind.

MR. P. EVANS expressed his agreement with Dr. Kirkaldy's comments, and congratulated the author on carrying out a much-needed piece of work. He hoped that Mr. Culling would indicate how the survey was carried out as it was important to know the probable errors of heights. Hitherto, the speaker had supposed that the effects of human interference with the courses of the rivers were sufficient to make it impossible to identify points at which changes of gradient occurred, but the author's results suggested that this was not so. The speaker thought that the uncertainties of the data were sufficient to make it preferable to obtain the logarithmic profile by graphical means rather than by elaborate calculation. He expressed some surprise at the author's suggestion that the terraces should not be taken into account, and referred to the terraces near Watford.

Mr. Evans enquired if the author has extended his work to the scarp valleys of the Chilterns which presented interesting geomorphological problems.

DR. HALLIMOND said they were indebted to the author for an extensive and detailed set of measurements. He had noticed that, in at least one case, the logarithmic relation had failed for a tributary while it was accepted for the main stream. How far was it possible for a tributary to enter a stream without disturbing the logarithmic gradient? Of course tributaries were of all sizes; in the Chilterns the valleys seemed to be rather long and narrow, but generally there might be great variety in the shape of the catchment area. Was it possible to indicate the most favourable conditions for obtaining a simple logarithmic gradient? Presumably the ideal curves could be represented as straight lines by logarithmic plotting; this might give a more sensitive illustration of the degree of coincidence with the observed values and might save space in printing.

MR. CULLING expressed his appreciation of the patient hearing and favourable reception of the papers, and his thanks for the pertinent criticisms and suggestions offered.

Some of the points raised had been covered in the papers and certain suggestions had been taken up already as lines of further research. In the main, the discussion concerned either the upper valleys or the use of extrapolated curves. On the first topic emphasis had been placed on an increase in stream volume associated with the advance of the Eastern Ice Sheet because this appears to be the most conservative hypothesis that covers all the field evidence. No doubt solution and mass-movement have occurred but cannot provide the primary cause of the marked division in the profile at the same stage in every valley. Solution and mass-movement of the valley slope cover would tend to obliterate all traces of a smooth valley profile whereas such reaches are found in the upper reaches—in one case (Harpenden Valley) up to the source. The division is between the lower reaches, where regular segments are separated by short knick-points or sections, and the upper reaches where regular and irregular sections occur unsystematically. Valleys which do not breach the scarp have preserved regular segments in their upper reaches much more frequently than do those that head in wind gaps. This suggests that melt-waters from ice in the Vale of Aylesbury are mainly responsible for the irregularity of the profiles.

The observation of Dr. E. H. Brown regarding the disappearance of knick-points in the upper parts of Welsh rivers was noted with interest, and in the near future it is hoped to be able to suggest why the elimination of knick-points occurs as a natural consequence of up-valley migration.

Apart from the period immediately prior to the Winter Hill stage of the Thames, two further periods can be detected during which the volume of the Chiltern streams was much greater than it is at present. Delta-building by a tributary on the floodplain of the main stream shows that in Taplow times (Chess and Gade), and in Floodplain stage times (Hambleden Brook), these rivers carried a much heavier load and had steeper gradients. The further suggestion of Dr. G. Dury regarding the effect of such changes in stream volume on the profile form has been the subject of further theoretical and practical work and it is hoped to publish the results shortly.

The idea of a local Chiltern ice-cap, suggested by Mr. S. A. Harris, is very attractive, and the evidence of chalk land-forms in areas not affected by periglacial conditions in the Pleistocene is of great interest. In the Chilterns V-shaped valleys of both symmetrical and asymmetrical nature do occur. The U-shaped valleys appear to have either the NW.–SE. consequent alignment or a N.–S. trend. The latter class of valleys has many peculiarities of distribution and morphology, and ice action cannot be ruled out as the responsible agent. George Barrow found evidence of ice action at Cowcroft and Prof. Hawkins, in an excursion report to this Association, proposed ice tongues extending through the Princes Risborough, Wendover and Tring Gaps. There is no doubt that small ice-caps existed on the Chilterns but the deepening of the middle portions of the valleys is attributable to the action of melt-waters rather than to the direct action of ice.

In connection with the extrapolation of profile curves there are much more sophisticated methods of curve-fitting; the normal procedure is to use a polynomial expression mainly because with such an expression any regular curve may be fitted to within any assigned degree of accuracy. However, the extrapolation of such an expression is dominated by the term of highest degree and its use is therefore vitiated. The logarithmic function is ideal for profile curve extrapolation for it approaches infinity exceedingly slowly and yet the first and second derivatives never vanish, a property shared by the two expressions derived by R. L. Goodstein and quoted by Prof. Miller. These expressions are empirical and satisfy no criterion of fit, so it is not possible to determine the probable errors in their use. However, it is the author's opinion that the rationalisation of the method of profile curve extrapolation should commence with the geomorphological problems, after which the mathematical procedure may be made more rigorous. Until the first part of this programme is finished the contention of Mr. P. Evans must be accepted.

In reply to Dr. A. F. Hallimond, the influx of a tributary, especially if it bears a heavy load, will tend to affect the gradient of the main stream, as is found to be the case at Croxley Green. Theoretically any discontinuous factor—whether tributary junction, rock-slide, spring action, or solution and seepage—will tend to influence the bed-gradient.

Shortly, it is hoped to publish an analysis of the prediction of past base-levels by means of extrapolated profile curves in which it is hoped to show that, in general, such curves do not trace the same path as the terrace profile and that, as a result, only in special circumstances do they provide reliable predictions of base-level and permit of correlation with terrace remnants. The predictions of base-level derived from the Chiltern stream profiles, though in some cases remarkable, are not as good as some speakers have suggested. Indeed, as Dr. Dury has remarked, they should not give any reliable results at all.

The Terraces of the Middle Thames

by K. R. and CATHERINE E. SEALY

Received 15 September 1954; read 1 June 1956

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ABSTRACT: An account is given of the river terrace succession in the Middle Thames area between Bourne End and Reading. Evidence is put forward to show that the succession established by Professor F. K. Hare in the Slough–Beaconsfield country can be traced upstream. The contrast between the incised valley of the Henley Loop and the wider spread of terrace relics in the Caversham–Henley district is noted. Finally, attention is directed to the abandonment of the old Caversham channel and to associated drainage changes in the Thames and its tributaries.

1. INTRODUCTION

THIS WORK on the terraces of the Thames between Bourne End and Reading was originally inspired by the studies of Professor F. K. Hare in the Slough–Beaconsfield country (1947). The long history of research in the Thames Basin was discussed most adequately in Hare's paper, so no detailed reference to this aspect is made here.

In the tract of country between Bourne End and the Colne Valley the Thames has shifted progressively southwards from its earliest course, so that the northern parts of its older flood-plains have been well preserved and present a full record of the morphological stages in the excavation of the valley. Thus, Hare was able to make a detailed geomorphological map based on the use of three facet types, (i) terrace surfaces, (ii) the bluffs separating each terrace, and (iii) the recent minor tributary valleys. West of Bourne End, however, conditions of preservation are far less satisfactory. Any attempt to record every facet in this area would result in masking of the terrace succession by a multiplicity of symbols. For this reason, only the terrace surfaces are shown in Fig. 1, and in order to render the final map comparable with that of Hare, only the surfaces in the area he covered, east of Bourne End, are represented. Finally, it should be noted that slightly degraded terrace forms are included on the map, in order that many significant features should not be ignored.

In the field mapping was carried out on the six-inch scale and the results transferred to 1:25,000 scale maps. Height measurement was an extremely important part of the work, and the validity of the results depended on its accurate determination. The minimum terrace interval is approximately 20 ft., so that an accuracy of 3–5 ft. was necessary. Where Ordnance Survey heights were in close proximity to a terrace surface, a short traverse with an Abney level provided an adequate value. In cases where this method was not feasible a surveying aneroid barometer was used. The method adopted aimed to eliminate the three main sources of error inherent in the instrument, (i) instrumental, (ii) calibration changes, and (iii) pressure fluctuations. To accomplish this, frequent checks on known heights were made within a closed circuit which could be covered in a short time and contained known heights well above and below that of the unknown point. This gave minimum errors in the conversion of pressures to heights. Equally important was the choice of weather conditions, which restricted observations to those periods when pressure changes were either small or regular in nature. As a final check, readings were taken on more than one occasion. The following example illustrates the method in greater detail.

Example of Height Determination by Surveying Aneroid Barometer

	Heights in Feet	
	Map (O.D.)	Aneroid Barometer
A. Mean of readings at three known heights in valley below a terrace to be measured ...	116.7	74.7
B. Reading on terrace on way up	—	296
C. Mean of readings at three known heights on hill above terrace	423.3	355
D. Reading on terrace on way down	—	302
E. Mean of readings at three known heights in valley below terrace (i.e. as at A)	116.7	81.7

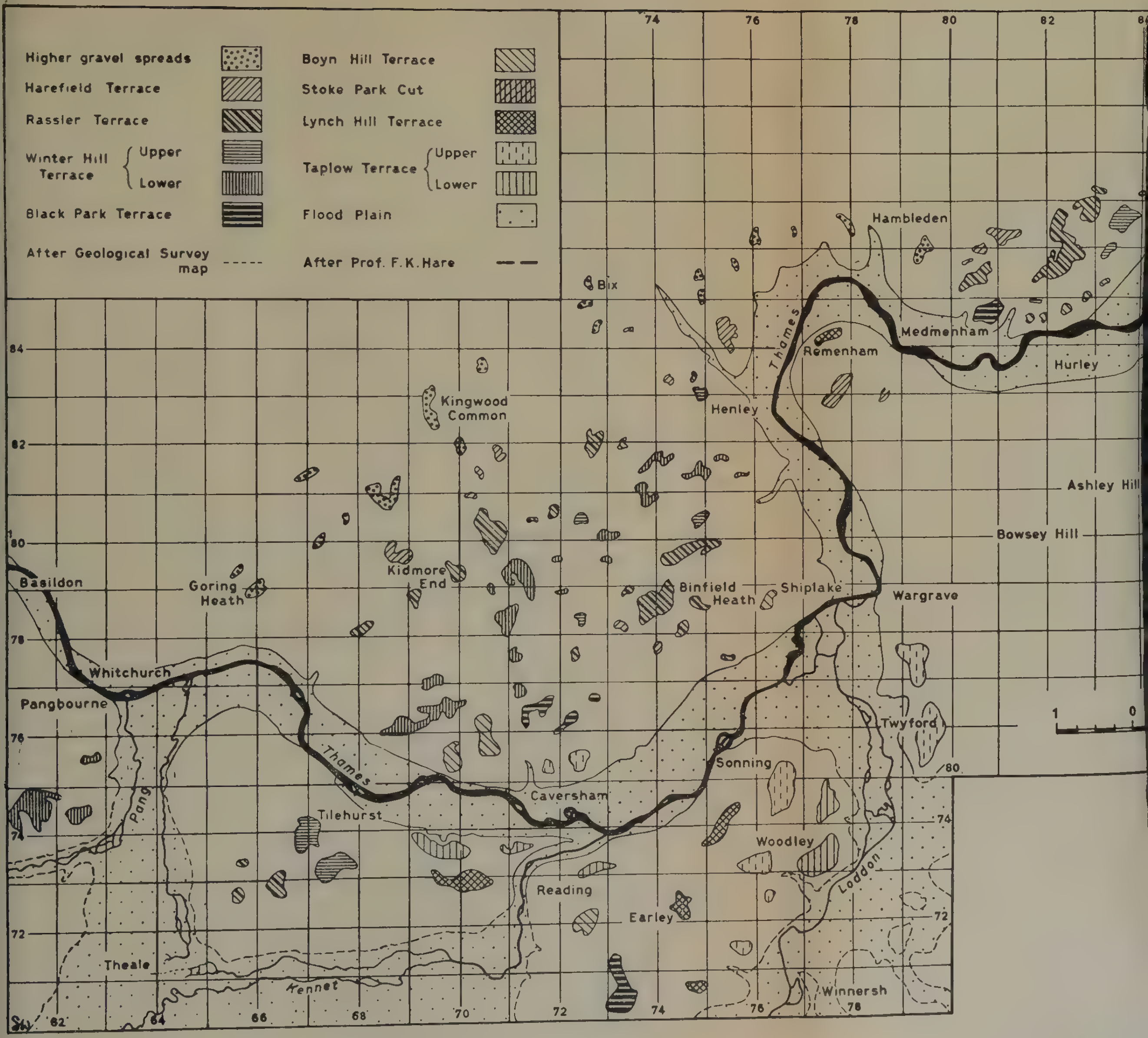
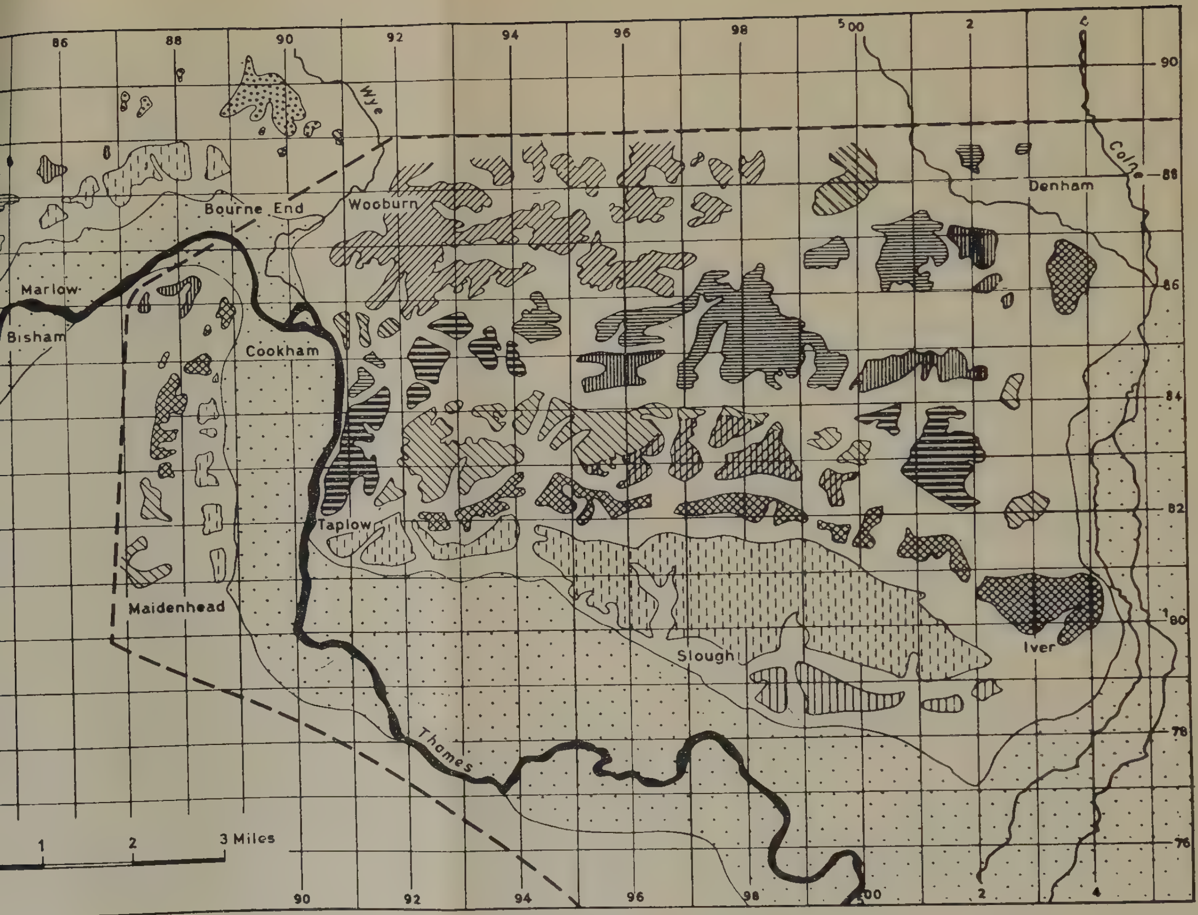


Fig. 1. The Terraces of the



Middle Thames

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	Heights in Feet	
	Map (O.D.)	Aneroid Barometer
Thus (a) Mean of A and E assumed to be the reading at time C	116.7	78.2
(b) Mean of B and D assumed to be the reading at time C	—	299
The height of the terrace is obtained as follows:		
(i) For an actual height 423.3−116.7 = 306.6	(Map)	
Aneroid barometer shows an indicated height of 355−78.2=276.8		
Therefore indicated heights must be increased by 10.8 per cent.		
(ii) Indicated height of terrace above valley is 299−78.2 = 220.8	1	
From (i) corrected height = 244.6	2	
Since 1 and 2 are heights above the valley, the *height of the terrace above Ordnance Datum* =361 ft.		

Repetition gave 359 ft.
Repetitions on other occasions gave 361 and 362 ft. O.D.

To facilitate reference to localities mentioned in the subsequent discussion, the Normal National Grid reference is given in all cases. The appropriate points may then be found either on the 1-inch maps of the Ordnance Survey (6th Edition), or from Fig. 1, which carries a National Grid overlay. In any particular instance, the full reference may be obtained by inserting '41/' in front of the given reference figures.

2. THE HENLEY LOOP COUNTRY

The Thames Valley between Henley and Bourne End forms a landscape unit which is strikingly different from the upstream and downstream portions of the valley. Beyond Henley the southern flank of the Thames Valley is broken by the wide flood-plains of the Loddon and Pang rivers, while the river gravels on the northern side extend several miles up the Chiltern dip-slope. However, between Henley and Bourne End, to the south of the present flood-plain, there is a steep rise in the Chalk, unbroken by any major through-valley, and reaching its maximum slope in Quarry Wood south-east of Marlow. Throughout the long period of its excavation the river has maintained much the same direction, and the incision of the river into the Chalk has prevented any marked uniclinal shifting. The tendency towards such a movement may be seen in the steep southern wall of the valley, and the preservation of terrace remnants on only the northern side of the present flood-plain. The dissection of the northern flank by numerous dry valleys has meant that the preservation of terrace relics is confined to the spurs separating these valleys. East of Bourne End the Thames escapes southwards, from its incised valley in the Chalk, to the Tertiary terrain of the Maidenhead–Slough area.

In the Henley Loop, to the south of the present flood-plain and its steep southern wall, are several extensive areas of Chalk sloping south-eastwards with a gradient of about forty ft. per mile. These smooth surfaces are remnants of the sub-Eocene floor, and are well seen in and around Maidenhead Thicket, north of Ashley Hill, and north-west of Bowsey Hill (Fig. 3).

(a) **High Level Features.** To the north of the belt of river gravels the Chiltern dip-slope presents the same complex assemblage of Tertiary outliers, Clay-with-Flints, Pebble Gravel and Pliocene beach deposits, which are found over much of the dip-slope. The majority of the river gravels of the Henley Loop lie below 400 ft. O.D., except for a degraded terrace relic at 428 ft. O.D., south of Crockmore Pond (748855). The rise at the back of this flat marks a distinct break from the predominantly rounded gravel on the flat, and the angular flints in red loam occurring along the Fawley spur. Southwards the ground drops away to a flattening at 390 ft. O.D. in Henley Park (749850).

This latter phase in the excavation of the valley is recorded on each of the five spurs between the Assendon and Hambleden Valleys within a height range of 380–405 ft. O.D. The repetition of the feature on each of these spurs suggests the presence of a once continuous feature, but accurate measurement of its height and form is made almost impossible by the deep dissection of the area. In several of the flats exposures showed well-rounded, medium-sized pebbles of both flint and Triassic rocks, in a very sandy matrix. In the case of the example in Ridge Wood (778866), dissection has so narrowed the spur that much of the drift has been removed and the number of rounded pebbles is small. This, together with the low height of the relic (380–384 ft. O.D.), suggests that the bench of the terrace has almost been reached, although no exposure exists to give the actual depth of the deposits.

Although this feature is well marked in the Henley–Hambleden area, it cannot be recognised confidently upstream. There is evidence for a 400-foot level between Henley and Goring, some seven miles from the features already discussed, but this is far too scanty for precise determination.

Downstream from Hambleden there are several high terrace relics which cannot be fitted into any scheme of correlation on account of their isolation. The highest are in Warren Wood and Bloom Wood (875895), at 375–380 ft. O.D. The surface soil shows a large number of rounded pebbles, many of Triassic quartz and quartzite, in a sandy matrix. A mile farther east lies the extensive surface at Flackwell Heath at 360–363 ft. O.D. Here the deposits show an interesting variation from a predominantly flint gravel on the Wye Valley side of the terrace, to a mixture of flint and

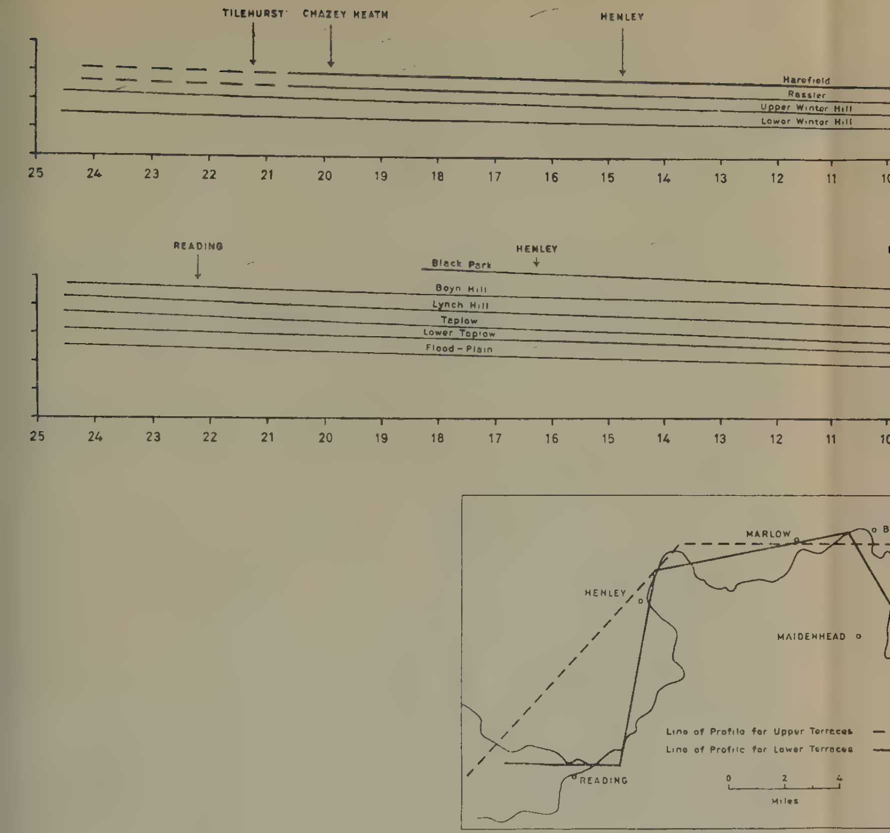

Fig. 2. Longitudinal profiles of the Thames Terraces bet

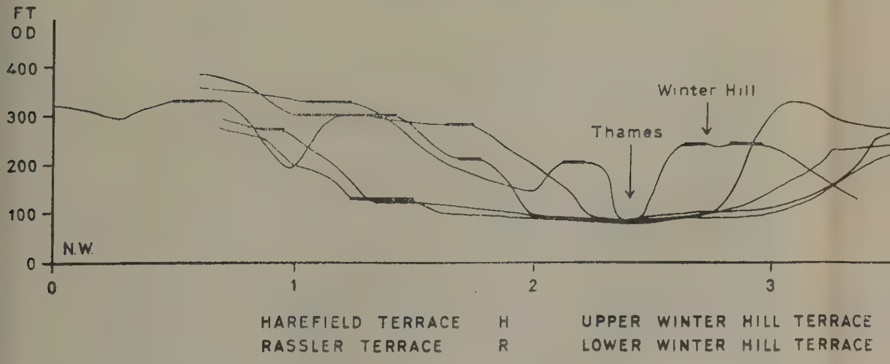

Fig. 3. Superimposed profiles of Henley

Triassic pebbles on the flank nearest the Thames. The flint gravel is best seen in the pits just off the surface itself, on Treadaway Hill (897903), although now no sections are visible. Formerly bedded river gravels of the flint and Triassic type could be seen in pits at the junction of Chapel and Sedgmoor Roads (894898). Pits west of Sedgmoor Cottages (895895) show masses of current-bedded sands separated by an irregular junction from structureless gravel containing sub-angular and rounded flints together with many large cobbles of Triassic quartzite and vein quartz. The pits lie on the degraded edge of the flat, and expose sections of solifluxion gravels. Possibly the persistence of the current bedding in the sands may be explained as due to temporary cementation of masses of these sands into boulders by interstitial ice, so that the bedding was preserved during the movement of the boulders.

The variation in the content of the Flackwell Heath flat shows that, in this neighbourhood, the Thames was joined by an ancestor of the Wye, which may explain the gravel surface of Juniper Hill (905893) at 373 ft. O.D. Here the gravel is predominantly flint, and it is possible that this higher ground is a part of the gravel fan formed at the junction of the proto-Wye with the Thames at this early stage. Fans are to be seen both in the Taplow and Flood-plain Terraces of the Henley Loop, and seem to provide the best explanation of the Juniper Hill deposits. In addition to these surfaces, small isolated remnants remain south of Sedgmoor Farm (896892), and north of Wilfrid Wood (899888), at 360 ft. O.D. The former, some 15 ft. below Flackwell Heath, may possibly represent the terrace bench obscured by only a thin veneer of gravel. Farther west a degraded relic exists on the spur north of Sheepridge (882902) at 360 ft. O.D. The deposits here contain a higher percentage of Triassic debris; a fact which may be explained by its position upstream and away from the Wye junction. Finally, an isolated remnant occurs at 365 ft. O.D. east of the Hambleden Valley near Burrow Farm.

(b) **Harefield Terrace.** The first well-marked terrace is represented by the flats at Bockmer End (810862), Remenham Place (777830) and No Man's Hill (753845). At Bockmer End the terrace surface lies at 334–336 ft. O.D. and is a very obvious feature in spite of its dissection by shallow depressions. On the opposite side of the Thames Valley there is a comparable surface at Remenham Place with an altitude of 335–337 ft. O.D. Here, as at Bockmer End, the surface soil shows mostly medium to small pebbles of flint, together with Triassic quartzite, vein quartz and several pieces of gneiss. Across the valley there is another terrace at 326–333 ft. O.D. on No Man's Hill, bevelling the end of the Henley Park spur. Steep slopes to the east, south and west of the terrace have resulted in the removal of the finer material from the gravel, and the surface is far more pebbly than either of the other two surfaces. The more intense 'washing' has lowered the flat, but has not appreciably altered its form, although it is broken by occasional small swallets.

Downstream from Bockmer End the terrace has been destroyed by the formation of more recent flood-plains, so that a direct connection with the Harefield Terrace of Hare (1947) is not possible. The remnants in the Henley Loop are too insignificant for any precise measurement of their longitudinal gradients to be made. Nevertheless, two sources of evidence strongly suggest the correlation. In the first place, the height relationship between this high terrace and the better preserved fragments of the lower terraces in the Henley Loop is such as to warrant the suggestion, while the upstream continuation of the gradient of Hare's Harefield Terrace supports the same conclusion. As the mean gradient for the stretch of the Harefield Terrace north of Maidenhead is 3–4 ft. per mile, the terrace should occur in the Henley Loop area at 338–348 ft. O.D. Apart from those already considered, no other terrace remnants occur in the area within 20 ft. of these two extremes.

(c) **Rassler Terrace.** There is abundant evidence of this terrace in the country west of Marlow at 300–307 ft. O.D. At Bockmer End the terrace is preserved at 305 ft. O.D., separated from the Harefield Terrace by a well-marked bluff. Across the Kingsbarn dry valley this same feature has been preserved along the top of the Rassler and Davenport Wood spur (823855). In spite of the narrowing of this spur, the terrace stretches along its top for a mile, with little variation in height, except where small valleys have almost cut through the spur, thereby lowering the level by two to three feet. On the northern edge a marked rise from the back of the terrace is found. Also, the back of the terrace is to be seen on the remaining two relics in Heath Wood (828868), and on the spur by the Orchards (831872). The gravel of the Rassler Wood spur has been worked to a depth of 15–20 ft., although no sections are now visible, while diggings just off the south-western edge of the Heath Wood surface expose Chalk at a depth of 15 ft. The Chalk has an irregular surface and shows evidence of solution and collapse in progress. It is overlain by large angular flints, a layer of sand, and finally by gravel in a sandy matrix. In content the gravel consists of rounded, angular, and sub-angular flints, with much Triassic quartzite, arkose and vein quartz. In form the gravel is structureless owing to its collapse into the Chalk pipes.

Farther east in the Henley Loop this terrace has been destroyed almost entirely, except for the small degraded relics at 290 ft. O.D. south-east of Hill Farm (850888).

In the area east of Bourne End, Hare (1947) recognised a sub-stage of the Harefield Terrace, some 25 feet lower, which he called the 'H_I' stage. Relatively little of this surface was preserved in the area owing to the depredations of the later Winter Hill flood-plain. The longitudinal gradient of this sub-stage—one and a half to two feet per mile—is considerably lower than that of the Harefield Terrace itself (Fig. 2). Projected upstream, such a gradient diverges from the Harefield Terrace, and places the expected height of the sub-stage at 300 ft. O.D., on the meridian of Bockmer and Rassler Wood. This agrees with the field evidence in the latter area and with the relative position of the surface in relation to the Harefield Terrace above, and the lower terraces below. The more decisive evidence to be found in the Henley Loop, together with the evidence of the country west of Henley, would seem to justify the recognition of this surface as a separate terrace. Since the feature is so well preserved in Rassler Wood, the name 'Rassler Terrace' is proposed in place of the 'H_I' designation of Hare.

Finally, mention must be made of a small bevel at 300 ft. O.D. on the Juniper Hill spur west of the Wye Valley (909890). The section in the brickyard on the edge of the flat is no longer visible, but a full description is given in an excursion report by Llewellyn Treacher (1916). He noticed that in spite of the terrace nature of the flat, the deposits were unlike any ordinary river gravel. The description of the section suggests a close similarity to deposits seen in the pit on the edge of Flackwell Heath at 361 ft. O.D. The composition of the gravels shows that the deposits of this lower flat belong to the proto-Wye, and probably represent the flood-plain of that stream in Rassler times. Since their deposition the gravels have been disturbed by solifluxion.

(d) **Upper Winter Hill Terrace (WH_2).** Remnants of a terrace at 270–280 ft. O.D. exist on the four adjacent spurs east of Rassler Wood, including the surfaces at Forty Green between 275 ft. and 280 ft. O.D., and on the Marlow Hilltop spur at 274–275 O.D. A small pit on the southern side of the latter surface exposes well-bedded river gravels. Hare considered that one of the chief features of the Winter Hill Terrace as a whole was the extremely low longitudinal gradient. A study of his long-profiles, and a careful measurement of the heights of the Terrace in the Slough area, suggest that this is so, but that the gradient of the WH_2 surface is greater than the lower WH_I surface. For the former the gradient is 1.5–2 ft. per mile, while for the latter the gradient is barely measureable—certainly less than one foot per mile. Calculations based on these findings place the expected height of the WH_2 or Upper Winter Hill Terrace in the Marlow area at 270–275 ft. O.D. (Fig. 2).

(e) **Lower Winter Hill Terrace (WH_I).** Downstream from Marlow Hilltop the Upper Winter Hill Terrace has been destroyed by the formation of a flood-plain which is 20 ft. lower at 252 ft. O.D. In turn this flood-plain has been almost destroyed by the later Taplow Terrace, so that very little remains, in fact. The chief remnant is at Harper's Heath (857886), while fragmentary evidence exists on the spur to the east of this point. On the basis of the relation of this evidence to that of the Upper Winter Hill, and the gradient characteristics of the Winter Hill Terrace farther east, these relics suggest a correlation with the WH_I, or Lower Winter Hill, Terrace. This conclusion is supported by the presence of the type-area at Winter Hill itself, on the opposite bank of the present river, at 249 ft. O.D.

(f) **Black Park Terrace.** Very little remains of this terrace in the Henley Loop, the chief remnant being on Bolebec's Castle Hill (810848) at 243 ft. O.D. In the Henley Memoir (1908) Osborne White records 6–12 ft. of stratified sandy, ferruginous gravel in a pit situated on a degraded portion of this surface. Further small bevels west of the Castle, at 240 ft. O.D. and to the east, at Danesfield at 239 ft. O.D., complete the picture. On such slim evidence correlation is difficult, but, as in previous cases, the relation of the terrace to its fellows places it within the range of the Black Park of the Slough area. In the latter area the Black Park has a longitudinal gradient of two and a half to three feet in a mile, which when continued upstream gives 245 ft. O.D. for the feature at Bolebec's Castle.

(g) **Boyn Hill Terrace.** From Danesfield (816845) eastwards, for a distance of a mile, each spur shows terrace relics at 214 ft. O.D. Beyond this point the Thames flood-plain swings north and the terrace relics are wedged out to leave nothing but a small break in slope by Oakengrove Orchard (835856). A direct projection of the Boyn Hill Terrace gradient in the Slough area (two feet in a mile) gives the expected height for this surface as 200 ft. O.D. at Danesfield. Since the Danesfield relics are considerably degraded, their present height is in fact several feet higher than one would expect, evidence that is confirmed by a comparison with the better preservation of the Boyn Hill Terrace nearer Reading. A partial explanation may be found by a comparison with the lower Taplow Terrace in the Henley Loop, where the surface has been built up by deposits from tributary valleys to form low fans. The presence of angular chalk flints in the deposits of the Danesfield relics, mixed with rounded pebbles and Triassic debris, points to a similarity with the Taplow Terrace. Downwash from the rises to the north of the relics would also contribute to the depths of the deposits at the present time.

(h) **Lynch Hill Terrace.** Within the Henley Loop only one terrace remains below the Boyn Hill and above the Taplow Terraces. This is the feature which cuts across the base of the spur on Remenham Hill (775842) at 185 ft. O.D. A roadside pit in the terrace shows a small section of bedded river gravels, while the Henley Memoir (1908) records an exposure of 10 ft. of well-bedded gravel, fine to medium in texture above, and very coarse below. In places the bedding was disturbed by settlement of the gravel into swallow holes which can still be seen in the chalk pit to the north of the terrace. In the Slough area the Lynch Hill Terrace has a longitudinal gradient of three to four feet in a mile, reaching a height of 150 ft. O.D. near Cookham Rise. Therefore the terrace should be found in the Remenham area at a height of from 177 ft. to 187 ft. O.D.; as close an approximation as the available evidence allows.

(i) **Taplow Terrace.** It is only between Marlow and Bourne End that the lowest terrace above the flood-plain has escaped destruction. Although cut up by dry valleys and degraded by the formation of swallets, this terrace is a very marked feature at 130 ft. O.D. At the entrance to each of the valleys of Marlow Bottom (858878), Winchbottom (867884) and Sheepridge Bottom (884885), a gravel fan grades into the 130-foot feature, and is cut into two parts by the lower floor of the dry valley. These fans rise as much as twenty feet above the general level of the terrace, with a surface drift of angular and sub-angular Chalk flint. There are no Triassic or rounded pebbles such as are found on the terrace surface itself. To the north of the dissected Winchbottom fan, on the east wall of the valley (867886), there is a river cliff with its floor at the level of the fan. Arrested dissection on the Chalk has preserved this feature after the valley was affected by rejuvenation.

Over the complete section the longitudinal gradient of the terrace averages three feet in a mile, a gradient that agrees with the Taplow Terrace near Slough. Here, Hare recognises his Upper or T_2 surface of the Taplow Terrace at 100 ft. O.D., some ten miles downstream from the Marlow Terrace. In addition, at Slough the Taplow Terrace is forty feet above present river level, a relationship that holds true for the Marlow area also. There seems little doubt that the terrace east of Marlow is the Taplow Terrace (T_2) of the Slough district.

The pit sections which have been observed in the Taplow Terrace near Marlow are of great interest. The Ferns gravel pit (883883) lies on a degraded part of the terrace by the entrance to the Sheepridge dry valley. This has been studied on several field meetings of the Geologists' Association (Treacher, 1916, 1924), although now it is inaccessible. According to these reports, forty feet of gravel was exposed there, the lower twenty feet of characteristic Taplow gravel containing broken and rolled flints and a few Triassic pebbles. All these were evenly bedded, except at the base where the drift was finer, more chalky, and with evidence of current bedding. The gravel was covered by a four-foot band of loam, and above this lay about ten feet of 'Rubble Drift' gravel. By this term Treacher meant an accumulation of angular and sub-angular flint gravel in a loamy matrix, with no sign of bedding. Other sections in the area showed a similar sequence of deposits. Presumably the loam is a brickearth, and its deposition seems to have continued during the accumulation of the Rubble Drift. The thickness and content of this suite of deposits indicate rapid deposition by streams from the Chalk slopes during a glacial period, when frost action and the lack of vegetation would aid a rapid supply of waste material. On reaching the Taplow flood-plain the lessening of the gradient brought about deposition of the material and the construction of the gravel fans. This view is strengthened by an exposure in the road cutting at 170 ft. O.D. between Marlow and Bovingdon Green (843868). The section shows five feet of Coombe rock overlain by three feet of brickearth. The junction between them, sharp and easily traced for a distance of forty yards, dips down the valley at an angle of fifteen degrees. The height of this section suggests that its deposition was coincident with the accumulation of the Taplow gravel fans.

(j) **Flood-plain Terrace.** This terrace is the only example which is continuous throughout the area, and has its back well marked everywhere. The surface of the terrace is complex, showing considerable variations in surface level. The longitudinal gradient is two feet in a mile (average) so that the terrace reaches 102 ft. O.D. at Medmenham.

Two further points need to be considered in connection with the survey of this terrace. Day Kimball recognised a knickpoint in the stream at Marlow, the solid bed of the Flood-plain dropping through a height of 35 ft. at this point (discussion on a paper by A. J. Bull, 1942). This knickpoint in the bench is not reflected in any respect by the surface form of the Flood-plain. In the area between Henley and Hambleden, fans similar to those found in connection with the Taplow Terrace occur in the Flood-plain. Near Mill End these fans are so close together that they form an almost continuous feature, and account for the great height of the back of the Flood-plain in this area. Whereas the Taplow fans were formed at a late stage in the evolution of the flood-plain, the fans near Henley represent a much earlier stage in the development of the Flood-plain. The same kind of chalky drift was found underneath the Flood-plain gravels near the Thames, and seems to follow the sides of the valley below the later deposits of gravel and alluvium.

3. THE HENLEY–GORING COUNTRY

This stretch of country is more interesting and more complicated than that of the Henley Loop, as just described. The Thames enters the structural unit of the London Basin at a height of 140 ft. O.D. through the Goring Gap, the only deep transverse valley occupied by a major river which crosses the Chalk outcrop of the Chilterns. The Thames then flows south-east towards Reading where it closely approaches the outcrop of the Tertiary beds. At this point the river swings north-east towards Wargrave, and thence north-north-west to Henley, gathering the waters of the Pang, Kennet and Loddon–Blackwater before reaching Henley itself.

Apart from the deposits of the present rivers, gravels laid down by their ancestors cover most of the extensive flats and slopes above the flood-plain. Moreover, gravel drift covers the dip-slope of the Chilterns and the Tertiary outliers of Chazey Heath, Emmer Green and Binfield Heath as far as a line from Basildon (610790) to Bix (728852). The landscape is very different from that of the Henley Loop, where only the Wye joins the Thames, and where each successive flood-plain has largely destroyed its predecessors.

(a) **High Level Features.** Here we are concerned only with the Plateau Gravels and Valley Gravels of the Geological Survey which occur below the 500-foot contour. Although there are extensive spreads of gravel between 350 ft. and 500 ft. O.D., few surfaces at these heights seem to represent terraces. This is hardly surprising when one considers that these high-level drifts must date from early Pleistocene times, and have suffered not only normal sub-aerial denudation, but erosion in a periglacial area during the glacial periods of the Ice Age. The drift, when visible, is often a stony clay rather than a sandy terrace gravel, and this, together with the evidence from exposures brought forward by Hawkins (1923), suggests the existence of ice in the area. The scarcity of recognisable terrace fragments, and the clayey matrix of these higher gravel spreads, cannot be taken as evidence against their original deposition by a river, but rather as indicating their greater age and disturbance by denudation during and since the Ice Age.

These gravels are the earliest drifts containing pebbles from Midland rocks. In fact, pebbles of quartzite and rose and white quartz are far more important than flint. The small percentage of the latter is mainly sub-angular and derived from the Chalk. The drift of the area near the southern approaches to the gap is often a stony loam containing abundant Midland drift, and extends as far south as a line along the dry valley separating the Upper Basildon–Pangbourne spur from that of Bere Park to the south. At the eastern end of the Pangbourne spur the typical flint deposits of the Pang cut across Gregory's Hill on the 275-foot terrace remnant.

From the morphological point of view the only relics that exhibit any kind of coherence are the single surface at 446 ft. O.D. at Kingwood Common (695826), and the flats at Satwell (705835), Bix and Crockmore Pond (748856) at 425–434 ft. O.D. Several small relics exist below this level but none is sufficiently well-marked to merit further description. In the western part of the Henley–Goring area the 400-foot contour roughly marks the position of the bottom of a fairly steep rise, the slope flattening below this level. Here at Goring Heath (660791), Kate's Cottage (683808) and Castle Grove, and at Kempwood Farm (673799) evidence exists for a terrace at 398–400 ft. O.D.

(b) **Harefield Terrace.** The recognition of this terrace, and its relationship with the downstream sections in the Henley Loop and the Slough–Beaconsfield country, is straightforward. The longitudinal gradient of three to four feet per mile agrees with the evidence already considered, while the general morphological form is easily recognised, with the back of the terrace present in at least two examples. At Shiplake Hill, Osborne White (1895) recorded 15 ft. of gravel with abundant Triassic debris and interbedded seams of reddish sands and loam. Near Binfield Heath the gravel contains a large percentage of angular and sub-angular flints, together with veined and liver-coloured quartzite pebbles, vein quartz and rounded flints from the Chalk and Reading Beds. The eastern part, which lies west of the George and Dragon Inn, Dunsden, shows many more rounded flints, fewer Triassic pebbles, and a large number of fragments of Lower Greensand chert. Probably this is an indication of the proximity of the junction of the proto-Blackwater with the Thames at this time.

(c) **Rassler and Winter Hill Terraces.** These three terraces—the Rassler, Upper Winter Hill and Lower Winter Hill—delineate the most interesting morphological feature of this area, i.e. the former course of the Thames from a point near Caversham direct to Henley. Over fifty years ago this trench was recognised by Osborne White (1895), and later by Llewellyn Treacher, who collected implements from the gravels of the valley floor for many years. Since then it has been considered in several important papers, notably Mrs. Ross (1932), Wooldridge (1938) and Arkell, Oakley & Treacher (1948). The present paper is concerned with the detailed morphology of this channel in relation to the older studies.

Taken as a whole, this channel shows relics of the three terraces already named. The floor is represented by gravel flats at 260–270 ft. O.D. which have become isolated from one another by the formation of the present dry valleys. The bounding walls are moderately steep and flatten out just above the 300-foot contour, where there are relics of a terrace at 315–325 ft. O.D. These are best preserved on the southern side of the valley, in the region of Binfield Heath (740785), where dissection is less pronounced than on the northern side. Finally, there is evidence of a third terrace between these two levels at 290 ft. O.D. (Fig. 4). Osborne White and Treacher regarded the gravels of the valley floor as contemporary with those of the Silchester plateau of the Kennet; a conclusion later confirmed by Mrs. Ross and Wooldridge, both of whom considered the floor to be of Winter Hill age. Treacher collected implements from the gravels of the channel, but unfortunately did not publish his results. After his death the collection was studied by Arkell & Oakley who termed it, ‘the largest and most valuable geologically dated assemblage of artifacts of Abbevillian and early Acheulian culture yet brought to light in Britain’ (1948). The assemblage of implements differs from that of the famous Boyn Hill site at Swanscombe (King & Oakley, 1936) by the absence of certain important middle Acheulian types. Although this assemblage does not necessarily imply that it is confined to the Winter Hill Terrace alone, it does represent the work of man at an earlier and more primitive stage of development; a conclusion which the morphological data supports.

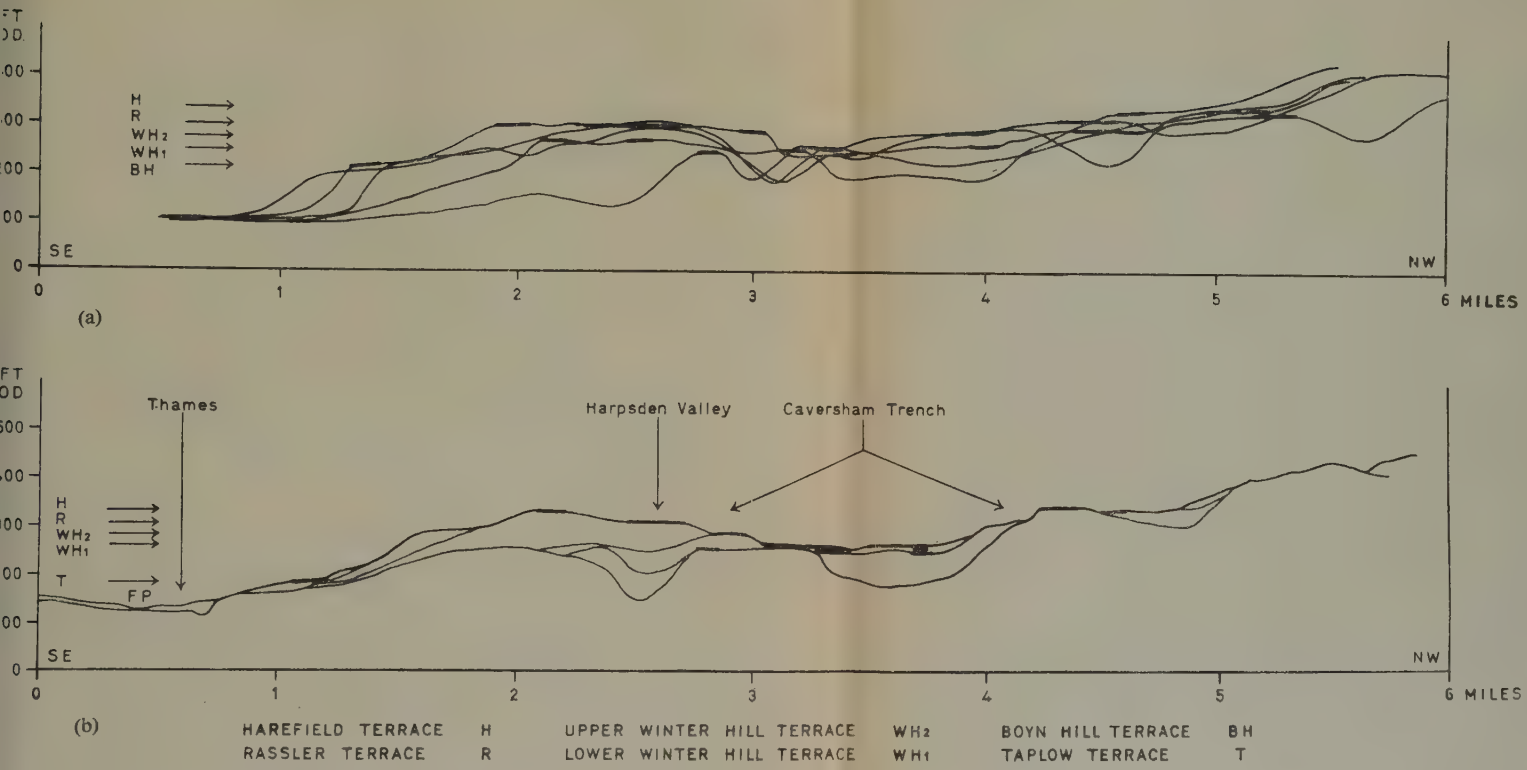

Fig. 4

(a) Superimposed profiles of the Caversham Trench

(b) Projected profiles of the Caversham Trench

[*To face p.* 380

The remnants of the Rassler Terrace as a whole have a height range of 307–323 ft. O.D. (see Fig. 1). At the Caversham end of the trench the terrace is represented by the degraded surface near Hodmoor Farm (683783) at 319 ft. O.D., and farther towards the north-east at Kidmore End at 307–310 ft. O.D. The remainder of the evidence on the northern side of the valley occurs south of Sonning Common and in the Rotherfield Greys district. The terrace is best preserved on the south side, in the Mays Green (746798) and Binfield Heath area (740785), at 304–315 ft. O.D. The gravels at Binfield Heath show a high percentage of well-rounded Triassic pebbles in addition to those of sub-angular flint. Treacher (1926) seems to have been one of the first to recognise the presence of Lower Greensand chert in the terrace gravels at Mays Green, where he noted eight feet of evenly-bedded gravel overlying loams of the Reading Beds. The gravel itself was a mixture of flint, Triassic debris and a small percentage of Greensand chert. This is important as it provides evidence for a river draining the Wealden area, or Southern Drift country, crossing the present line of the Thames Valley (which could not have existed then) and joining the Rassler Thames near Mays Green. The river concerned must have been the proto-Blackwater. Apart from flint pebbles, the gravels of the flat near Rosehill Kiln (723773) contain abundant Triassic debris and small percentages of other sedimentary rocks and igneous rocks. The matrix is a reddish and loamy sand, the whole section of 3–7 ft. overlying the Tertiary beds.

In the type-area at Rassler Wood the Rassler Terrace is at 306 ft. O.D., and its longitudinal gradient is three feet in a mile in both the Henley Loop and the Slough–Maidenhead country. The direct measurement of the gradient in the Caversham–Henley area is not possible since many of the remaining surfaces and rock benches are indifferently preserved. A prolongation of the downstream gradients to the Caversham–Henley area gives a height of 327 ft. O.D. for the terrace. The difference in height between the Rassler Terrace and the Upper Winter Hill Terrace in the Slough area is 25 ft., while in the Henley Loop it is 25–30 ft., and if the present correlation is correct, is about 35 ft. in the Caversham channel. Since the gradient of the Winter Hill Terrace is extremely low, this result may be looked upon as at least circumstantial evidence in favour of the correlation. The chief basis for the latter must be the relation of this terrace to the Winter Hill surfaces which can be considered more precisely.

(d) **Upper Winter Hill Terrace.** Very little now remains of this terrace, and its correlation with the downstream sections must rest on its relation with the Lower Winter Hill Terrace. The most marked relics occur north of Bellehatch Park (748803), at 284 ft. O.D., and at the western end of Crowsley Park (725804), at 290 ft. O.D. No sections in the gravels are available, and no records of previous excavations exist. On the basis of gradient characteristics downstream the expected height for the terrace in the Bellehatch Park area would be 286–294 ft. O.D.

(e) **Lower Winter Hill Terrace.** The floor of the channel has not been occupied by the Thames since Lower Winter Hill times, but since that date it has been dissected by numerous dry valleys and does not appear as a continuous flood-plain, in consequence. Nevertheless, there still remains abundant evidence from which the nature of the terrace may be ascertained. A study of the map (Fig. 1) shows the full extent of the remaining relics. We may concentrate our attention on the drift deposits and the morphological evidence as a whole. At the upstream end of the channel, near Blagrave's Farm (696763) and Chazey Wood (687760), a much-dissected remnant exists at 267–270 ft. O.D. The Reading Memoir of the Geological Survey (1903) notes a section in a pit near the former point exposing eighteen feet of stratified gravel containing sub-angular flints, a few rounded flint pebbles, quartz pebbles and large red quartzites up to seven inches in length. The matrix of sand and sandy loam was not prominent. Farther east, near Farthingworth Green (701766), the same memoir records ten feet of similar drift, and there are further records for the flats near Kennylands (713795) and Highlands Farm (736813).

The height range for the surviving parts of the flood-plain, including the more highly dissected remnants, is 253–271 ft. O.D. When the preservation of the individual flats is studied more closely, it becomes apparent that the longitudinal gradient of the terrace surface from Caversham to Henley is very low indeed, being approximately one foot in a mile. This result may be checked by comparison with downstream conditions—particularly with the Slough–Maidenhead area mapped by Hare (1947). As already noted, Hare considered the longitudinal gradient of the Winter Hill Terrace to be very low; indeed, according to him 'it hardly exists'. Nevertheless the gradient of Hare's upper sub-stage (H_2) is greater than that of the lower (H_1), so that the two surfaces diverge upstream—as the evidence from the Henley Loop area shows (Fig. 2). For this reason, backed by the relics in the Caversham–Henley district, the two sub-stages of Hare have been considered as two separate terraces of the Thames in this paper. In the case of the Lower Winter Hill Terrace a projection of its longitudinal gradient near Slough gives an expected height for the terrace surface of 257 ft. O.D. at Henley. No allowance is made for an upstream steepening of gradient. In any case, on the evidence from the Caversham–Henley channel floor, it is likely to be very small. Thus the correlation of the floor of the old channel with the Lower Winter Hill Terrace is defensible from more than one standpoint. This is important because the terrace must form the 'base' for the correlation of the other less well-preserved terraces in the Caversham–Henley country.

(f) **Black Park Terrace.** At the end of Winter Hill times the Thames

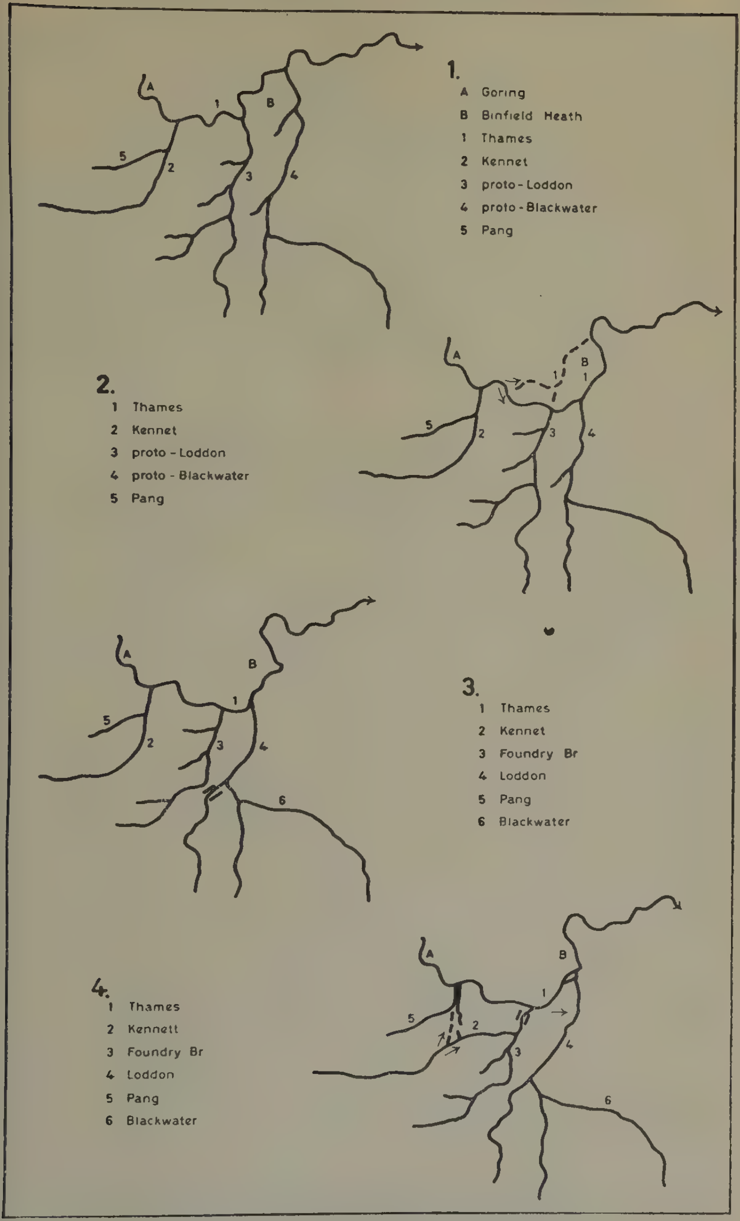

Fig. 5. Drainage changes in the Thames Valley between Henley and Reading from Winter Hill times to the present day

flowed in its well-developed valley subsequent to the margin of the main outcrop of the Tertiary beds from Caversham to Henley (Fig. 5). Near Harpsden it was joined by the proto-Blackwater which drained the Southern Drift country and brought the fragments of Lower Greensand chert to the gravels of the main valley of the Thames. This brings us to the crucial point as to why the Thames abandoned this channel for the more circuitous route to the south which it has followed from Black Park times to the present day. Near Slough, and in the Henley Loop, the Black Park Terrace is a strong feature with a longitudinal gradient of three feet in a mile. An upstream continuation of this terrace should be found at 272 ft. O.D. near Reading, i.e. at the same height as the Lower Winter Hill Terrace. If an allowance is made for a steepening of the gradient upstream, the Black Park and Lower Winter Hill Terraces should merge somewhere between Henley and Reading.

We can visualise the knickpoint of the Black Park rejuvenation working upstream past Henley to the junction of the Thames and the proto-Blackwater. The Thames itself flowed directly from Caversham to this point; a valley cut in the Chalk. The proto-Blackwater flowed past Cressingham (733707), and thence probably by way of Sonning (757755) to Harpsden and the Thames, a valley cut entirely in Tertiary strata. Thus it is feasible that the knickpoint worked upstream more rapidly along the Blackwater Valley. The question now remaining to be considered is what happened in the vital area between Sonning and Reading? Insufficient evidence survives for the full story to be worked out, but what does remain is suggestive.

East of the main line of the former Winter Hill Valley of the Thames, and curving round the southern margin of the higher ground of Binfield Heath and Rosehill, there are relics of a former flood-plain at 270–272 ft. O.D. East of Hemdean Bottom on the top of Gravel Hill (712768) a marked flat exists at 265 ft. O.D., and although no sections are visible in the gravels, from the Geological Survey map the deposits appear to rest directly on the Chalk. This may well represent a southern patch of the Winter Hill Terrace. Two further relics, at Caversham Grove (715764) and Caversham Park (724763) at 272 ft. O.D., again show no sections in the drift at present, but the Reading Memoir records eight feet of sub-angular flint and flint pebble gravel near Caversham Grove, and nine feet at Caversham Park. In neither case was the base of the drift reached. Both flats rest on an outlier of the Reading Beds, which is further suggested by the reddish, loamy nature of the drift matrix. Their southerly position, together with the evidence already given, suggests that these relics represent the Black Park flood-plain at the stage of initiation of the present Thames Valley. The significance of this evidence on the drainage changes in the Sonning–Reading area will be discussed at a later stage.

(g) **Boyn Hill Terrace.** Although the exact story of the desertion of the Caversham trench may be obscure, nevertheless it is certain that it was abandoned in Black Park times, since the next terrace in the succession, at 230 ft. O.D. in the Reading area, shows that the Thames was then following the present drainage line. At St. Peter's Hill, Caversham (705754), a large remnant exists at 227–230 ft. O.D. which is now largely built over, but Shrubsole (1890) recorded a depth of eight feet of slightly bedded flint gravel with quartz, quartzite and sandstone pebbles in a sandy matrix. Further flats occur on Southern Hill (726720), south of the river, at 225–228 ft. O.D., and in the Shiplake district at 220–223 ft. O.D. Evidence is too fragmentary for the calculation of gradient characteristics, but the relation of the terrace to its predecessors, and the projection of the downstream gradient of the Boyn Hill Terrace to the area, both suggest its correlation with that terrace.

(h) **Lynch Hill Terrace.** This terrace is very indifferently preserved. Save for one surface near Reading (702728), at 200 ft. O.D., most of the relics belong to the Loddon Valley. The identification of the Reading surface as Lynch Hill in age must depend upon its relationship to the older terraces and to the better preserved Taplow Terrace below. The absence of the Lynch Hill Terrace in the Henley Loop area, with one exception, makes any link with the type area, near Slough, almost impossible. In the case of the Loddon a similar difficulty must also be present. The interest in these relics lies in their drift cover. The first occurs at 206 ft. O.D., south of Sonning (753741). Here the Reading Memoir records nine feet of gravel resting on Reading Clay. The deposit is stratified, and consists mainly of sub-angular and rounded flint, with Triassic debris, and a few fragments of Greensand chert. The second surface is found on Woodley Hill, Earley (746724), at 210–212 ft. O.D. Here the drift consists of 12–15 ft. of gravel with many Greensand fragments, but no Triassic debris. The difference between the deposits of these two areas suggests that Woodley Hill is a relic of the Loddon Valley, whilst the Sonning flat lies near the Thames–Loddon junction, and thus contains the characteristic drift of both rivers, i.e. the Triassic debris transported by the Thames, and the Greensand debris transported by the Loddon. The line of the Lynch Hill Loddon Valley is further delineated by a terrace fragment at 215 ft. O.D., west of Home Farm (748707).

(i) **Taplow Terrace.** The position of the Lynch Hill and Taplow Terraces, between the present Thames and Loddon rivers, suggests the easterly shift of the junction of the two streams. The line of the Lynch Hill surfaces is succeeded, to the east, by a similar north–south line of terrace remnants at approximately 180 ft. O.D. The inter-terrace fall is thus about thirty feet, and thus similar to the bluff drop between the Lynch Hill and Taplow Terraces in the Slough region. The terrace at 170–180 ft. O.D. is very well developed on both sides of the Loddon (Fig. 1). The Charvill Hill gravel pit, near the terrace at Butt's Hill (765745), shows well-stratified gravels with many quartzite pebbles, which suggests that the Thames–Loddon junction must have been in the neighbourhood at this period.

On the eastern side of the Loddon Valley there are two more quite extensive terrace remnants at 168–171 ft. O.D. at Ruscombe (795760) and by the Floral Mile (793774). The Ruscombe gravels have been described by Treacher & White (1901) as consisting of sub-angular and rounded flints with a number of red and brown Bunter quartzite pebbles and rounded pieces of Lower Greensand chert. In places on the north side of the pit, gravel of Thames type was seen to be overlying gravel of the purely southern drift, suggesting successive flood-waters of the Thames and Loddon. At some points the stratification was disturbed by oblique piping into the underlying Reading Beds, but elsewhere the gravels were distinctly stratified, and the deposit clean and sandy. Treacher assigned these gravels to the Boyn Hill Terrace (1896), a correlation presumably based on the contained implements, since it is untenable on morphological grounds. In its type area at Boyn Hill, eighteen miles downstream, the terrace lies at 170 ft. O.D., so the Ruscombe gravels cannot be assigned to this terrace.

A morphological study of the evidence suggests that the terrace forms part of the Upper Taplow Terrace (T_2). Moreover, Treacher noted that at the base of the Ruscombe gravels were 'some very large unrolled flints of a size greater than any ordinary stream could move along a clay floor, and probably dropped by melting ice'. The implication of cold climatic conditions accords well with the views of many geologists that similar conditions prevailed in the Lower Thames during this period. The Upper Taplow Terrace is preserved farther upstream, in Caversham Park Place (723754), and by St. Anne's School (717752), at 185 ft. O.D.

The Lower Taplow Terrace (T_I) is well seen at Reading aerodrome (775933), and at Norris's Green (775743), at 148 ft. O.D. In Reading, despite artificial levelling, there are undoubted relics of the Terrace at 145–155 ft. O.D. some thirty feet above the present river. At the junction of Alexandra Road and London Road (728732) the Reading Memoir of the Geological Survey records a temporary exposure of fifteen feet of brown sub-angular flint gravel resting on Chalk, while some yards to the south Chalk was reached at a depth of ten feet. This shows that the bluff rise begins near this point, and supports the line of the southern boundary of the Terrace, which boundary can be fixed, morphologically, only with difficulty. Also it is interesting to note that the gravel itself was small for the most part, but near the base there appeared a large whitish patch of coarse flint gravel lying at a considerable angle, unstratified, and chiefly made up of stones from four to eight inches in diameter. These basal deposits seem to resemble solifluxion deposits, suggesting cold conditions in early Lower Taplow times. Further support for this view is given by Poulton (1880) in a description of a pit, east of Reading School (728727), at 155 ft. O.D., where besides the gravels themselves, remains of such cold species as *Elephas primigenius*, *Bos primigenius*, *Equus fossilis* and *Rhinoceros tichorhinus* were found.

(j) **Flood-plain Terrace.** The flood-plain of the Thames falls from 140 ft. O.D. in the Goring Gap to 110 ft. O.D. at Henley, and is adequately shown on the Geological Survey maps. In consequence, no attempt has been made to supplement this work on a morphological basis, except for some minor alterations. The deposits associated with the flood-plain include gravels, alluvium and loam.

In most cases the gravel represents the earlier phases of deposition, and by their structure suggest cold climatic conditions. Thus, the Reading Memoir records a section near the mouth of the Kennet (731737) showing sixteen feet of well-stratified gravel resting on the Chalk. The bulk of the deposit consists of sub-angular and rounded flints, together with small pebbles of chalk, fragments of Eocene shells, and numerous pebbles of quartz and quartzite. The presence of normally friable chalk pebbles and Eocene shells, in addition to little-worn flints, strongly suggests rapid deposition by a stream in flood. Finally, we may note that in the Reading–Sonning stretch of the flood-plain in many places the sub-angular flint gravel is overlain by a yellowish-brown loam, usually about five feet thick, and probably representing the upstream equivalent of the brickearth of the Lower Thames.

4. DRAINAGE DIVERSIONS IN THE READING–HENLEY AREA

Within this area evidence exists for three modifications in the drainage pattern. By far the most striking is the diversion of the Thames from the Caversham–Henley channel to its present course. Secondly, the presence of Greensand chert in the Loddon–Blackwater gravels indicates that the present Loddon is not the key stream in this group of Thames tributaries. Most recent of all is the diversion of the Kennet from the Theale–Pangbourne channel to its present course through the Coley gorge at Reading.

Of these three changes, only the first directly concerns us here. Any explanation of the abandonment of the Caversham channel must take into account certain facts. The floor of the channel is known to be of Lower Winter Hill ($\mathrm{WH_I}$) age, while, as previously noted, its western end also approximates to the calculated height of the Black Park Terrace at that point. The succeeding Boyn Hill Terrace follows the present course of the Thames. In Winter Hill times, any stream flowing through the Caversham trench would be incised in the Chalk, whereas a river flowing south of Binfield Heath would probably still be excavating in Tertiary strata, e.g.

Blackwater. Also, we must note the depth of the gravels in the Caversham channel and the establishment of their riverine character by H. J. O. White & others. Neither must we lose sight of the relationship of these gravels with the widespread Kennet drifts of comparable age. Moreover, while the latter show a gradient of ten feet in a mile over most of their length downstream of Newbury, a break in gradient to five feet in a mile, and less, occurs near the Thames–Kennet junction.

The presence of Greensand chert is restricted to gravels lying south of Binfield Heath. This helps to place the position of the only stream which had access to such material, the proto-Blackwater. Finally, we must remember the tendency towards southward uniclinal shifting in the Henley–Reading area. The presence of high ground from Mays Green in the north-east to Emmer Green in the west, separating the Caversham channel from the present Thames, forbids any direct shift in the course of the river. As important is the fact that no such high ground separates the two channels south-west of Emmer Green.

The most reasonable explanation of the Thames diversion stems from the ideas of H. J. O. White which are quoted in the paper of Arkell, Oakley & Treacher (1948). Briefly, he considered that during the Winter Hill aggradation, possibly associated with a building-up of the gradient with respect to the lower reaches of the river, the Thames overflowed into a new channel east of Caversham and joined the proto-Blackwater. Water then flowed on both sides of Binfield Heath until later events confirmed the southern channel.

We may expand this idea by visualising the Thames in Winter Hill times—most likely coincident with the First Interglacial—as a broad stream following a course through the Caversham channel. Any tributary flowing into the Thames would be likely to suffer some reduction in gradient, and this may help to explain the nature of the Kennet gravels. Let it be said that a closer study of these gravels is required before we can do more than suggest the possibility. The deposition of copious waste by the Thames, aided by lateral corrosion directed particularly against the southern bank, caused the overspilling of the river into the valley of the proto-Blackwater to form a course on either side of Binfield Heath. There may have been a small stream draining into the proto-Blackwater near Sonning which aided the diversion but this is not an essential feature.

The onset of cold conditions associated with the Black Park rejuvenation would result in the upstream migration of a knickpoint which would tend to make greater headway in the southern Tertiary channel than in the Chalk valley of the Caversham trench. The result would be the eventual abandonment of the latter in favour of the easier southern channel (Fig. 5).

This explanation is open to criticism, since no certain evidence of the Black Park Terrace now exists at either end of the old channel. Nevertheless, the available evidence is accounted for, and the explanation offered seems the most likely one.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Professor S. W. Wooldridge and to Mr. P. Evans for advice and criticism during the course of the work. They are particularly indebted to Mr. Evans for his help in the use of the surveying aneroid barometer.

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DISCUSSION

PROFESSOR S. W. WOOLDRIDGE said he very warmly welcomed the completion by Mr. and Mrs. Sealy of their work with which he was familiar in its earlier stages. The work was a direct sequel and confirmation of that by Professor F. K. Hare which had been commended by him to the Association ten years before.

He felt that the most important feature of such work was its method of mapping and recognising terraces in the field. Sometimes it was complained that Geomorphology was too inexact and non-quantitative to claim full rank as a scientific discipline. It was therefore worthy of note that the only really measureable element of a terrace was its surface—not the rock floor beneath it, the position of which was commonly unknown. Nevertheless the interpretation of terrace surfaces must involve some clear and definite theory, hardly to hand at present, of what is meant by the 'grading' of a stream course. Without such a theory it was difficult to know how to interpret the former long-profiles of streams based upon terrace surfaces.

In conclusion Professor Wooldridge said he would like to ask the authors concerning their conclusions about the Black Park Terrace recognised by Professor Hare. His own work in recent years inclines him to think that this terrace was a very important stage in general Pleistocene chronology.

PROFESSOR F. K. HARE said he was happy that his first visit to a meeting of the Association in seventeen years should have coincided with a discussion of the Thames terraces. He congratulated Mr. and Mrs. Sealy on their paper, which made an important contribution to our knowledge of the evolution of the river. He was particularly happy that his own work in the Beaconsfield country had been so competently followed up.

Three points interested him in particular. One concerned the authors' identification of terrace—fans on the upper surface of the Taplow Terrace near Bourne End. How did this bear upon the active deepening at times of arctic climate? A second point concerned the upper Blackwater. There was a chert-bearing gravel train, sloping east to the Black Park level of the Mole–Wey area, from Bracknell to near Egham. He had assumed that this channel had carried the Blackwater drainage in Black Park times and earlier. Could the authors discuss this point? Finally, he was highly interested in the suggested mechanism for the diversion of the Thames from the Caversham–Henley channel. In a similar fashion a minor aggradation of the modern flood-plain near Twyford would make possible an overspill of Thames water through the Waltham–Shottesbrooke–Maidenhead clay lowland, and presumably this, in turn, would lead to the abandonment of the Henley loop. Hence the authors' hypothesis was perfectly consistent with modern physical possibilities, though other mechanisms for the diversion were possible.

PROFESSOR A. A. MILLER congratulated the authors on completing a piece of morphological mapping in territory that presented greater difficulties than either the Kennet Valley upstream from Reading or the Thames Valley downstream from Bourne End, especially in the identification of terminal surfaces and in the precise fixing of the altitudes of breaks of slope at the terrace edges. He asked for fuller information on the methods employed in determining the mean height of each terrace surface shown in the reconstructed longitudinal profiles at each recognised stage. In particular, he asked for the basis used in applying statistical methods, pointing out the difficulties inherent in the use of either numerical frequency or area as criteria of the form and altitude of the initial surface.

DR. FRANK HODSON referred to an investigation into the composition of the gravels of the 150-foot terrace as made by himself and Miss P. S. Walder, the preliminary results of which had been communicated to the British Association for the Advancement of Science in 1954. He recalled that three types of gravel assemblage had been recognised. One was composed almost entirely of flint pebbles and was deposited by the Kennet; another contained a proportion of 'Northern Drift' and was laid down by the Thames, whilst the third was characterised by chert and had been emplaced by the former Blackwater. The investigation had enabled a reconstruction of the main drainage channels of the Reading area to be plotted for the time corresponding to the formation of the 150-foot terrace.

Also it had been shown that there was a very large drop in the percentage of 'Northern Drift' in the gravels of the 150-foot terrace, as compared with higher terraces. A variety of explanations had been considered to account for this phenomenon; the most plausible seemed to be that the fan gravels of the Chiltern scarp had commenced about the time of the 150-foot terrace and had diluted with flint the Thames gravel above the Goring gap, thereby reducing the percentage of exotic material.

The investigation was still proceeding and it was hoped to publish the results soon. In the meantime the map showing the distribution of the terraces which was provided by the authors would be of very considerable service to all interested in this and allied topics. He congratulated the authors upon the successful conclusion of their researches into this rather complicated area.

MRS. TREACHER said she was interested to hear that no foreign material had been found in the Kennet Valley. In the last century a Mr. Rickard was Sanitary Engineer at Newbury when the main drainage of that town was laid. He published a paper in the *Proceedings* of the Geological Society in which he stated that he had seen 'quartzites' on the High Terrace of the Kennet. Mrs. Treacher did not know what he meant by 'High Terrace'. By 'quartzites' presumably he meant Bunter material. It is very desirable that these quartzites should be searched for.

Mrs. Treacher could not agree with the authors' statement that Ruscombe Terrace is Taplow. Her husband collected very beautiful implements from the Ruscombe Terrace. The Taplow Terrace has never been known to yield anything in the least like them. Also, if this is Taplow then what is the terrace at 130 ft. which extends from the foot of the Ruscombe Terrace to the banks of the Loddon? It is overlain by brickearth, and displays all the usual characteristics of the Taplow Terrace. The level 175 ft. O.D., quoted by the authors as that of the Boyn Hill Terrace is Upper Boyn Hill, but Ruscombe Terrace is Lower Boyn Hill.

DR. J. D. SOLOMON said that he felt a little sceptical about the detailed reconstruction of terraces from so many scattered fragments as this involved the assumption that there had been absolutely no warping—an assumption which he felt to be unsafe. He pointed out that the Triassic material had been introduced at a very early date, occurring as it did at 550 ft. O.D. on Streatley Golf Course. Unless there had been another influx at a later date, which seemed doubtful, it should be possible to estimate the relative ages of gravels locally by comparing the degree of its dilution with flint from sources within the London Basin, and he inquired whether this was the case, in fact. He also inquired whether chert from the Greensand was introduced at this stage; did it occur, for example, in the high-level gravels on Ashley Hill? The authors had described the gravels as terrace deposits throughout; was there anything to correspond to the gravel trains or 'deckenschotter', as Prof. Wooldridge had described them, farther down the valley?

MR. AND MRS. SEALY, in replying, thanked members for the interest they had shown in the paper.

To Professor Wooldridge they were grateful for his contribution and endorsed his warning that much still remained to be done in connection with theoretical aspects of stream development. Regarding the Black Park Terrace, it was almost completely absent in the area reviewed, but the authors noted it was probably in Black Park times that the present course of the Thames was finally established between Reading and Henley. Also one should not overlook the fact that its place in the terrace sequence lay between the widespread Winter Hill and Boyn Hill Terraces.

The authors wished to record their pleasure in presenting their results in the presence of Professor F. K. Hare, whose work in an adjacent area formed the starting-point for the present survey. The terrace fans near Bourne End were minor depositional features occurring at the junction of small streams which drained the Chiltern dip-slope with the Thames. The deposits themselves suggested that the material was brought down by the streams during periods of partial thaw. The question of the Blackwater drainage had not been covered in the field.

Professor Miller's questions about methods employed underlined the need for further research in this field. The methods adopted by the authors were based on those of earlier workers, but an attempt had been made to adapt statistical methods to the problem. Some progress had been made and it was hoped that the results would be made known at a later stage. The attention of students of the subject might well be drawn to American efforts in this field; notably to those of Dr. Strahler.

Dr. Hodson's remarks on the gravels of the Reading area were most encouraging and the authors hoped that he would soon be able to publish his results.

In reply to Mrs. Treacher the authors wished to draw attention to the fact that the Boyn Hill and Lynch Hill Terraces occurred at 165–170 ft. and 150 ft. O.D. respectively, eighteen miles downstream from the Ruscombe district at Maidenhead. Therefore, the Ruscombe gravels were almost certainly part of the Taplow Terrace (T_2). No feature had been mapped between Ruscombe and the Loddon. It would appear that the feature referred to by Mrs. Treacher lay within the Flood-plain Terrace, which showed considerable minor relief in the area concerned.

The authors felt that Dr. Solomon's fears regarding warping in the area were completely unwarranted, as had been demonstrated by the work of Professor Wooldridge and others many years ago. The term 'gravel train' simply implied a spread of river gravels that in some instances might be differentiated morphologically into distinct terraces. The authors had no knowledge of the content of the Ashley Hill gravels.

Late-Glacial drainage in part of North-East Wales

by C. EMBLETON

Received 1 June 1956

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ABSTRACT: The characters and distribution of certain late-Glacial gravels in North-East Wales are described. The gravels build rough deltaic terraces which indicate the existence of former lakes in the area up to a height of 658 ft. O.D. The higher lakes were impounded by both Welsh and Irish Sea ice, and the various channels which provided outlets for the lakes are examined.

1. INTRODUCTION

THE OCCURRENCE of extensive deposits of sands and gravels in certain valleys of north and central Flintshire has often been noted by local geologists, and particularly by A. Strahan in his Geological Survey Memoir of 1890. The distribution and general nature of the deposits were carefully described in this Memoir, but there was little or no discussion of their origin or significance. It is fairly clear, however, that Strahan recognised the deposits had been sorted and laid down by water. The purpose of this paper is to reconstruct certain stages in the drainage of the area at the close of the Glacial period, from the evidence provided by these sand and gravel deposits and certain other landscape features.

The valleys containing the deposits belong to two separate drainage systems at present—those of the Alyn and the Wheeler (Fig. 1); these two systems are separated by a hardly perceptible col (at 510 ft. O.D.) near Star Crossing. The Wheeler drains westwards to the Vale of Clwyd, while the Alyn flows generally south-eastwards downstream from Mold to join the Dee at the Cheshire border. The whole course of the Alyn may be conveniently divided into three sections: the Upper Alyn from its source to Pont Cilcain, the Alyn Gorge from this place to Rhydymwyn, and the Lower Alyn below Rhydymwyn. In this paper we shall be concerned principally with the valleys of the Lower Alyn and the Wheeler.

2. THE NATURE AND DISTRIBUTION OF THE LATE-GLACIAL GRAVELS

Usually the deposits found in these valleys consist of stratified sands and stony gravel. Nearly always the stones are smooth and well-rounded; most of them are from local Ludlow or Lower Carboniferous rocks. The sands, which often occur as bands or lenses in the deposits, are fine in texture, and show well-developed current-bedding in fresh exposures. One of the most common types of sand has a very distinctive bright red colour, noted by Strahan (1890, pp. 129–30). The only possible source for this red sand is the Triassic sandstones of the Vale of Clwyd, for the red sand occurs in greatest profusion in the lower Wheeler Valley, and when traced up the Wheeler Valley (away from the Vale of Clwyd), it becomes less common, and the red colour less intense. Nevertheless, the red sand can be traced out of the Wheeler Valley, across the Star Crossing watershed, through the Hendre Gorge (Fig. 1), and down the Lower Alyn Valley as far as Mold, before its colour fades completely. The distance from the Vale of Clwyd to Mold is about eleven miles.

The current-bedding of the sands, and the rounding of the pebbles, indicate that the deposits as a whole were laid down by water. The water currents which moved the pebbles must have been fairly powerful, as rounded pebbles up to seven or eight inches in diameter are not infrequent. On the other hand, the dips of bedding in most of the sand deposits are often steep—up to 30°–35°. Such dips are characteristic of deposition in standing or slow-moving water. Taken as a whole, the evidence points to the existence of lakes into which the deposits were carried by powerful and fast-moving streams, and built out as deltaic formations. The red sand content has almost certainly been derived from drift containing much Triassic material, brought up from the Vale of Clwyd by Welsh Ice which advanced eastwards.

The approximate age of the sand and gravel deposits can be given now, and further suggestions made at the end of the paper. The fact that the stratification of the gravels has not been disturbed by ice-advance means that the deposits are later than the last glaciation to affect these valleys. On the other hand, the frequency of kettle-holes and other irregular depressions in the gravels points to the burial and subsequent melting of ice-masses in them, and these facts suggest that deposition of the gravels took place in the retreat stages of the last glaciation affecting the area. In the Wheeler Valley, tufa deposits, probably of early Neolithic age (Jackson, 1922), always overlie the sands and gravels; both tufa and gravels are being eroded by the present streams. Altogether, a late-Glacial age for the gravels seems very probable. At such a period numerous melt-water streams from local ice-masses and glaciers would be carrying heavy loads derived from the glacial drift and depositing them wherever the flow was checked—as, for example, if they emptied into ice-dammed lakes.

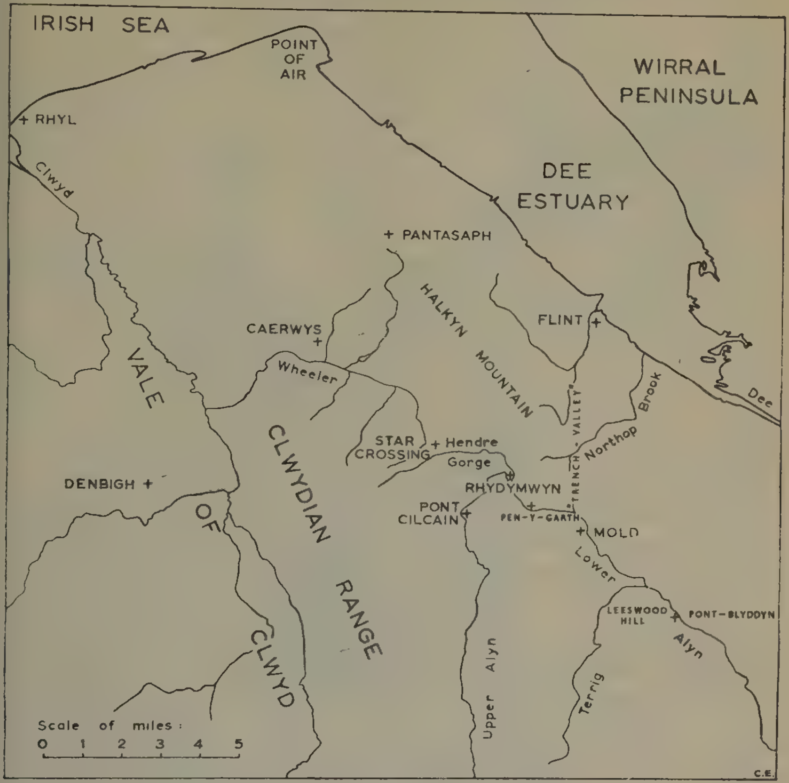

Fig. 1. Outline of the present river-system of North-East Wales

The general distribution of the gravels considered in this paper is shown in Fig. 2. It can be seen that the principal accumulations occur in the Wheeler and Lower Alyn Valleys, while the gravels also spread northwards from the Wheeler up the Afon Pant-Gwyn Valley, and northwards from the Lower Alyn up a line of valley which will be termed the Mold-Flint trench-valley (a descriptive term adopted by officers of the H.M. Geological Survey, *Summ. Progr. geol. Surv. Lond.* for 1911, p. 16; *Summ. Progr. geol. Surv. Lond.* for 1912, p. 19). In height, the gravels range upwards to 800 ft. O.D. on the southern end of Halkyn Mountain, but rarely above 550 ft. O.D. in the lower and middle Wheeler Valley, or above 500 ft. O.D. in the Lower Alyn Valley below Mold.

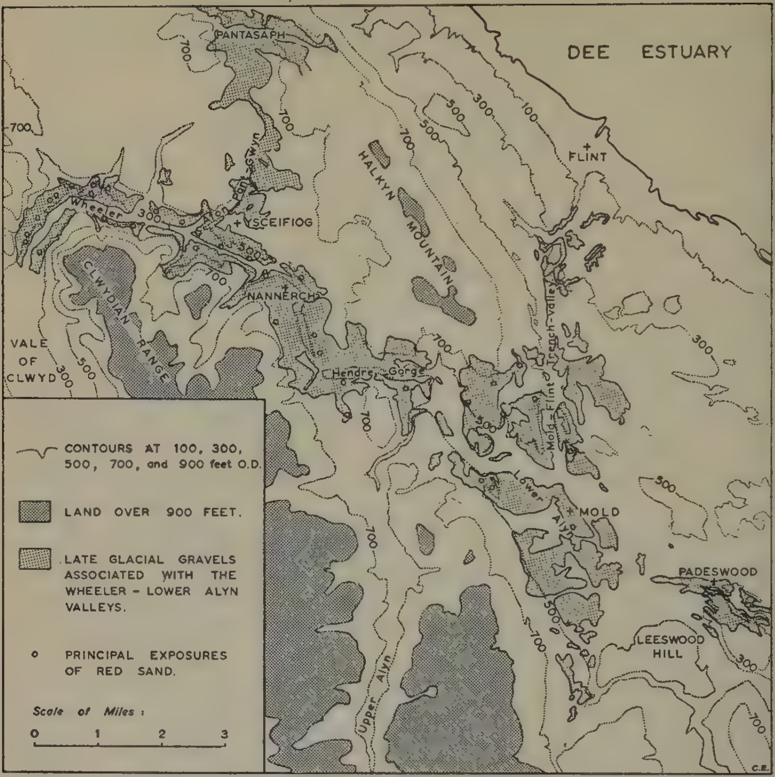

Fig. 2. Late-Glacial gravels in part of North-East Wales

3. THE GRAVEL TERRACES

The most remarkable feature of the gravels is the way in which they are built into a series of terraces, some of which can be traced over considerable distances along the valleys, with no significant change of height apart from detailed imperfections due to kettle-holes or stream dissection. The following terraces have been mapped in the field, using six-inch maps. Their distribution is shown in Fig. 3.

(a) **620–640 ft. O.D.:** from Ysceifiog, in the Wheeler Valley, to the middle of the Mold-Flint trench-valley, a distance of six miles. The terraces can be traced through the Hendre Gorge (connecting the Wheeler and Lower Alyn Valleys), but they do not occur either west of Ysceifiog or south-east of Mold.

(b) **520–540 ft. O.D.:** extending for about five miles between Nannerch and the neighbourhood of Mold, though it may be represented west of

Nannerch by the numerous hillocks in the Wheeler Valley which rise to 500–520 ft. O.D.

(c) **460–480 ft. O.D.:** restricted to the Lower Alyn Valley, downstream almost to Leeswood Hill (about three miles).

(d) **410–420 ft. O.D.:** a doubtful feature in the Lower Alyn Valley around Mold.

(e) **A series of irregular terraces** in the Lower Alyn Valley, sloping downstream, and lying at thirty to forty feet above the present river. They

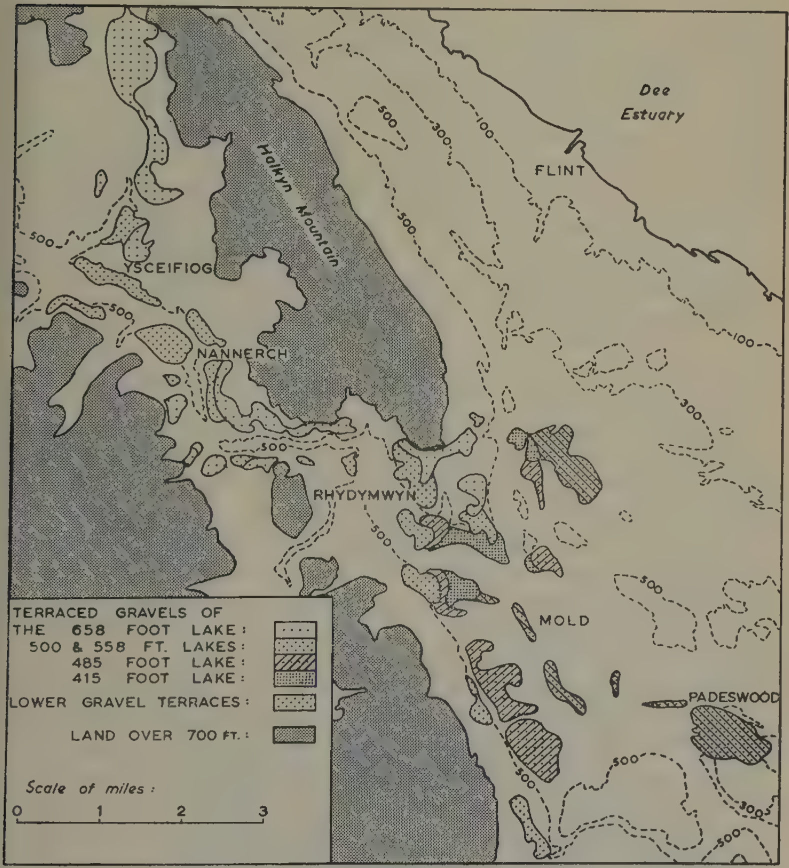

Fig. 3. The late-Glacial terraces of the Wheeler and Lower Alyn Valleys. *In places, especially in the neighbourhood of former ice-fronts, the gravels form irregular features, and boundaries of different terraces are sometimes difficult to determine in the field. Hence, the divisions given on this map must be regarded as approximate*

appear to merge into a broad platform of pitted gravels around Padeswood, with an average surface at 320 ft. O.D.

The first three of these terraces are approximately horizontal over distances ranging from three to six miles. The fourth terrace is too restricted to be of any value, while the fifth probably belongs to a former thalweg of the Lower Alyn. The horizontality of the first three terraces, together with the fact that relatively steep dips can be seen in the materials forming them, points to deltaic deposition by numerous streams draining into a series of lakes held temporarily at three different levels. In view of the late-Glacial age of the gravels it is thought that the lakes were formed behind retreating ice-barriers, and that the lakes fell to successively lower levels as retreat of the ice uncovered different outlets. However, the lake-levels cannot be fixed with any precision on the evidence provided by the gravel deltas alone, for although in undisturbed deltas the outermost edge usually corresponds to lake-level, clearly the terraces in the Alyn–Wheeler Valleys have been affected by subsequent erosion which removed the original outer edge. Moreover, as will be demonstrated later, probably the original deltas had underwater extensions, so that the outer edge was some small depth below lake-level. Such underwater extensions might develop, for example, if the stream entering the lake was carrying a large quantity of very fine material which set up muddy suspension currents in the lake (Bell, 1942).

4. FORMER LAKE-LEVELS AND ASSOCIATED SPILLWAYS

To determine the former lake-levels precisely we must investigate the outlets which controlled the lakes. These outlets are not difficult to find; a fine series of overflow channels can be seen two or three miles north of Mold (Fig. 4), and a deeply cut channel, now mainly dry, runs round the south and west of Leeswood Hill (Fig. 2). But the highest lake in the Alyn–Wheeler Valleys—that in which the gravels of the 620–640-foot terrace were deposited—drained over an entirely separate col. This col lies at the head of the Afon Pant-Gwyn Valley, near Pantasaph, at a height of 658 ft. O.D. where solid rock is exposed. The evidence for the use of this col as an outlet lies in the extension of vast gravel deposits up the Afon Pant-Gwyn Valley from the Wheeler (Fig. 2), and in the fact that there are no other cols within fifty feet or more of this height which could conceivably have provided an outlet for a Wheeler–Alyn lake to lower ground. The fact that sometimes the gravel terraces extend downwards to 620 ft. O.D. can only reflect the fact that the original deltas had underwater extensions; it is most unlikely that the delta surfaces have been significantly lowered by subsequent erosion, as in many cases these surfaces are still remarkably even.

The outlet controlling the second lake-level, corresponding to the

520–540-foot terraces was almost certainly the Sarn Galed channel, two miles north-north-west of Mold (Fig. 4). The channel is deeply incised and of great capacity, and follows a winding course; for part of its length, its floor has a gradient of only 1 in 230. The highest point in the floor is at 558 ft. O.D. Coal Measure sandstones are exposed near this point. Once again the associated gravel terraces in the Wheeler and Lower Alyn Valleys are some few feet lower than the lake-level at 558 ft. O.D.

It is interesting to note that at Quarry Farm the Sarn Galed channel lacks an eastern wall for a short distance, and the present small stream

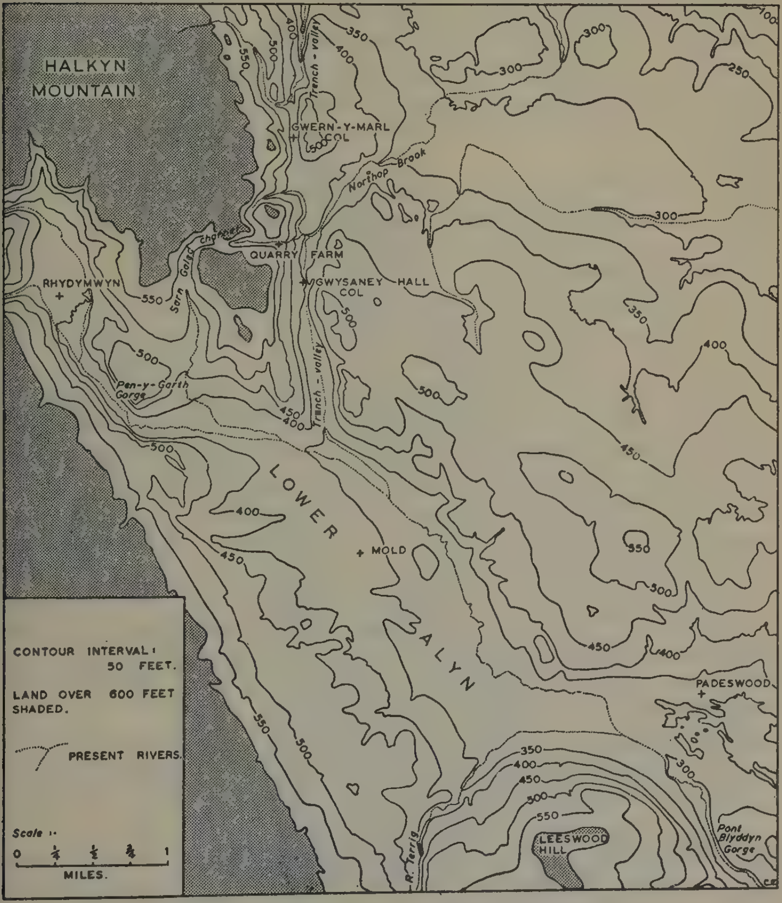

Fig. 4. The relief of the country around Mold

escapes eastwards out of the channel at this point. It seems likely that an ice-front once provided the valley-side here, as the floor of the channel continues northwards to its outfall without interruption.

The two lake-levels at 658 ft. O.D. and 558 ft. O.D. must have been continuous from the Wheeler Valley to the Lower Alyn Valley through the Hendre Gorge. But once the lake level had fallen to around 500 ft. O.D. or lower, the Wheeler and Lower Alyn Valleys would each contain separate lakes, for the watershed at Star Crossing rises to 510 ft. O.D. at present. There is some drift here, though it is not likely to exceed a few feet in thickness, judging from the form and altitude of neighbouring rock exposures. Thus it becomes clear as to why the 460–480-foot gravel terrace is restricted to the Lower Alyn Valley. At the time of formation of this terrace the Lower Alyn lake was separate, though it may well have received drainage from a Wheeler lake over the Star Crossing col at about 500 ft. O.D. There are, in fact, many gravel mounds in the Wheeler Valley rising to just over 500 ft. O.D. which may be remnants of deltas built out into such a lake.

The outlet for the Lower Alyn lake in which the 460–480-foot gravel terraces were formed appears to have been the deep channel running past Sarn Adda round the south of Leeswood Hill, towards Coed Talon (Fig. 5). Once the site of this channel may have been the course of the River Terrig (Wedd, 1924). The highest point of the alluvial floor of the channel is now 492 ft. O.D. though the solid rock may be a few feet lower (about 485 ft. O.D. judging from the slopes of the valley-sides).

The Sarn Adda channel was abandoned when the trench-valley north of Mold came into use. The trench-valley (Fig. 4) at present possesses two watersheds along its floor—at 398 ft. O.D., near Gwysaney Hall, and at about 430 ft. O.D. (an alluvial fan) near Gwern-y-Marl. The rock-floor is not exposed at either watershed, but it is estimated (from adjacent exposures) to lie at 390 ft. O.D. and 415 ft. O.D. respectively. When the higher col was in use, the Lower Alyn lake stood at about 415 ft. O.D. and drained northwards along the trench-valley towards Flint. At a slightly later stage the outlet in the side of the trench-valley (now utilised by the Northop Brook) was uncovered, just south of the Gwern-y-Marl (415-foot) col, so that the Lower Alyn lake fell slightly to 390 ft. O.D. (controlled by the Gwysaney Hall col: see Fig. 4).

Finally, the Lower Alyn lake drained completely south-eastwards down the present Lower Alyn Valley, though not precisely along the pre-Glacial course of the Lower Alyn river, as will be seen later.

5. THE FORMER POSITIONS OF ICE-BARRIERS IN THE REGION

It now remains to discuss the positions of the ice-barriers responsible for holding up the various lakes. In the case of the lake-levels higher than the

Star Crossing watershed two major ice-barriers must be postulated, and from general knowledge of the glaciation of this part of Wales they were supplied by the local Welsh Ice to the west and south, and the Northern or Irish Sea Ice on the east and north. At its maximum extent the Irish Sea Ice must have ascended the northern slopes of Halkyn Mountain to heights of at least 950 ft. O.D. (Strahan, 1886), blocked the Lower Alyn Valley as far upstream as a point one mile west of Mold (Mackintosh, 1879), and pressed hard against the flanks of Leeswood Hill.

The highest lake at 658 ft. O.D. was formed when there was still such a barrier of ice from Halkyn Mountain to the uplands south and south-west of Mold, preventing any drainage whatever to the east (Fig. 5, stage 1). At the same time, Welsh Ice must have blocked both the Wheeler Valley and any possible route to the north-west past Caerwys, forcing the lake to drain north over the Pantasaph col.

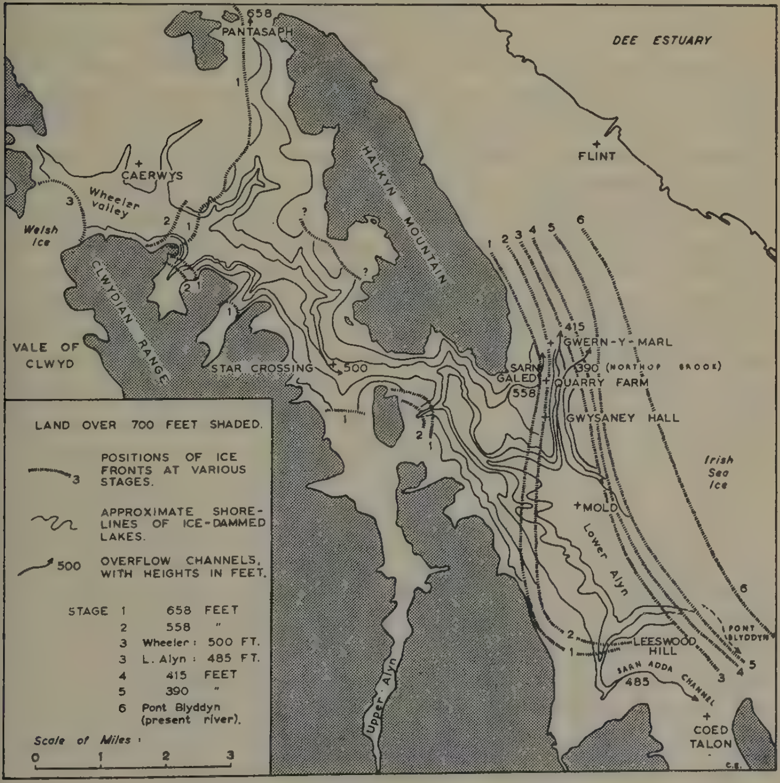

Fig. 5. Late-Glacial lakes in North-East Wales

Lowering of the lake-level occurred when the Irish Sea Ice retreated very slightly eastwards (Fig. 5, stage 2), uncovering a gap at the site of the Sarn Galed channel. Welsh Ice must still have been present in the Wheeler Valley to a height of at least 558 ft. O.D.

Another slight retreat of the Irish Sea Ice away from the uplands south of Mold brought the Sarn Adda channel into use; there was now a separate lake in the Lower Alyn Valley (Fig. 5, stage 3). Almost certainly there was still a barrier of Welsh Ice in the Wheeler Valley, but there were then only two possible outlets for a Wheeler lake—over the actual ice-barrier, or over the Star Crossing watershed at about 500 ft. O.D. into the Lower Alyn lake. Lake-levels in the Wheeler Valley below 500 ft. O.D. were solely determined by the height of the Wheeler ice-barrier, therefore, and probably were very variable.

In the Lower Alyn Valley, eastward retreat of the Irish Sea Ice opened up the line of the trench-valley from Mold towards Flint, giving rise to a lake at about 415 ft. O.D. which escaped northwards over the Gwern-y-Marl col (Fig. 5, stage 4); not long afterwards, continued withdrawal of the ice-front enabled the lake to drain through the breach in the eastern side of the trench-valley where the Northop Brook now takes its course (see Fig. 4, and Fig. 5, stage 5).

Eventually the ice retreated sufficiently to allow the Lower Alyn lake to drain away completely (Fig. 5, stage 6). It was replaced by the River Alyn, still swollen with melt-waters, and the former gravel deltas were exposed to attack and partly re-distributed. In at least two places, however, the river found itself slightly displaced from its original position by the gravels, and in cutting down through the gravels, encountered solid rock outcrops at Pen-y-Garth and Pont-Blyddyn (Fig. 4). Locally the river thalweg was graded to each of these rock bars, and above each spreads of gravels accumulated. When the rock bars were eventually severed the river thalweg fell to a lower level still, leaving the gravel spreads above each bar as terraces which rise above the present river.

6. CONCLUSION

Several interesting points emerge from this study of the late-Glacial gravels. The lakes in which the highest gravel deltas formed were maintained by both Welsh and Irish Sea Ice, showing that some of the retreat-stages of both these ice-sheets in this area were more or less contemporaneous. It is also clear that the western margin of the Irish Sea Ice must have remained in close contact with the flanks of the Flintshire uplands for some time during the de-glaciation (see Fig. 5), in order that a lake should be impounded to heights of at least 658 ft. O.D. and forced to escape to the north.

In studying the gravel deltas associated with the lakes it has been shown that the outer edges of these deltas usually extended as much as twenty or thirty feet below lake-level as determined from the overflow channels. It was suggested that suspension currents in the lakes might be responsible, but this remains an hypothesis at present. Studies of other areas, where close correlations can be made between delta-remnants and overflow channels dating from late-Glacial times, might provide further evidence.

The remarkable changes in the size and cross-sectional form of the Lower Alyn Valley have been explained by slight displacement of the Lower Alyn's course, due to the vast quantities of gravels deposited in the valley. During the draining of the Lower Alyn lake the river had its course developed across successively exposed gravel deltas and, in effect, was locally superimposed on the underlying solid rocks around Pen-y-Garth and Pont-Blyddyn with the downcutting of its thalweg. At these two places the Lower Alyn Valley assumes a gorge-like form, but above and below each the valley widens into basins the widths of which vary from half a mile to over one mile.

Finally some further suggestions can now be made on the dating of the gravel deposits described in this paper. As the gravels have not been disturbed by ice-advance since they were laid down they must be the result of valley-blocking by the last ice-sheets to invade this area. The most recent major glaciation in North-East Wales seems to have been roughly of Magdalenian age (Arkell's Cymrian II; Arkell, 1943): a drift of this period sealed up certain caves in the Vale of Clwyd which contain traces of occupation by Aurignacian man and this drift must have come from the north since it contains marine shells. The ice-sheet bringing the drift must have been of considerable thickness (the caves are up to 250 feet above the floor of the Vale) and of some power to penetrate seven or eight miles into Wales from the Irish Sea. Since we have no evidence of any more recent glaciation in North-East Wales which affected areas below 700 ft. O.D. or thereabouts, it seems likely that this ice-sheet may have been part of the one which, on the other side of the Flintshire uplands, penetrated south towards Mold and blocked the Lower Alyn Valley. Therefore, the gravels which accumulated in its retreat-stages are possibly of late-Magdalenian age.

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Field Meeting at Alum Bay and Colwell Bay, Isle of Wight

28 and 29 April 1956

Report by the Director: DENNIS CURRY

Received 13 September 1956

THE PARTY of seventeen members and friends assembled at Yarmouth, Isle of Wight, and then proceeded to Totland Bay by bus. From there they walked to the Royal Needles Hotel at Alum Bay where lunch was taken. A magnificent view was seen from the hotel grounds. To the right, across the Solent, was Hurst Castle and the cliffs at Barton and Bournemouth, with Poole Harbour and the Purbeck Hills in the distance; to the left were the chalk stacks of the Needles at the end of the promontory of Farringford Down. The Director then gave a brief account of the geological structure of the Isle of Wight and its relation to that of the Isle of Purbeck and the Hampshire mainland. He mentioned, too, some of the special features displayed by the contiguous cliff sections of Alum Bay and Headon Hill, in which are to be seen most of the Lower Tertiary horizons which occur in England.

From the cliff top the party went down the chine and turned left along the beach to view the cliffs of Alum Bay which range in height from 150 ft. to 300 ft. The whole of the strata exposed in these cliffs are vertical, or nearly so, and the Eocene beds, which consist of sands, clays and lignites, are of the most varied colours. They are an imposing sight, and it is not surprising that they attracted the attention of the earliest geologists.

At the southern end of the beach rises the dip-face of the Chalk, here at the horizon of the *mucronata* Zone. The Chalk was found to be rather unfossiliferous, but one member of the party found a fine *Lima*. Overlying the Chalk are the Reading Beds, consisting of about 80 ft. of mottled clays, predominantly brick-red in colour. The junction-bed is a sandy clay with small numbers of rounded or sub-angular flints which rests on a deeply-piped surface of the Chalk. Some of the pipes appeared to be six feet or more in depth and two or three feet across. The surface of the Chalk was not bored, however.

Another junction-bed was seen above the Reading Beds. Here, a few feet of glauconitic sand rests on the mottled clays, and contains derived pebbles of clay, with sharks' teeth and marine mollusca. This is the local representative of the Basement Bed of the London Clay. In Alum Bay the

London Clay is of loamy 'Hampshire facies' and contains one or more thick beds of sand. A few fossils were found, though these were not well preserved. White (1921, p. 97) included over 400 ft. of beds in the London Clay at this locality, but the Director pointed out that only the lowest 200 ft., or so, contained beds of the typical grey-blue silty clay. He considered that some of the higher beds, referred by White to the London Clay, might be of Cuisian age.

Above the London Clay are over 700 ft. of beds of controversial origin. They include green, red, yellow and white sands, and white, grey, brown and black clays, with several beds of lignite. These are the famous coloured sands which are so attractive to non-geological visitors. These beds are referred in part to the Bagshot Beds and in part to the Bracklesham Beds. They include the famous Alum Bay Leaf Bed, from which members of the party secured a few faint leaf impressions.

Succeeding the coloured sands is a thick series of dark marine clays, more or less glauconitic and sandy, which contains several fossiliferous horizons. There is a well-marked bed of rounded flint pebbles at the base. Although the whole forms one continuous series, the lowest 48 ft. are referred to the Bracklesham Beds, and the upper 190 ft., or so, to the Barton Beds. The Director explained that this followed as a result of the arbitrary definition of the base of the Barton Beds as being situated immediately below a bed containing *Nummulites prestwichianus*. This bed was located by the party, and proved to be crowded with small, flat nummulites. The Middle Barton Beds were well exposed immediately south of the remains of the pier, and were seen to be very fossiliferous. Most of the characteristic fossils may be found here, though they are not as well preserved as those from the type locality on the mainland. To the north of the pier the Headon Hill Sands of Upper Barton age were well seen. Here, also, it was clear that the dip of the beds was changing rapidly from the vertical characteristic of most of Alum Bay to the horizontal of Headon Hill.

At this point the party left the beach and climbed the seaward face of Headon Hill. Upwards, the unfossiliferous Headon Hill Sands soon gave way to the richly fossiliferous Lower Headon clays and limestones, with *Limnaea*, *Planorbis* and other freshwater mollusca. Still higher in the succession was the prominent bluff of the white Upper Headon limestones, also freshwater; and between these two freshwater series were seen the pale green and sepia estuarine sands and clays of the Middle Headon Beds. Here the party spent some time in collecting from fallen blocks and weathered faces which latter yielded a rich harvest. Attention was drawn to a lignitic band within the Upper Headon limestones, which might possibly be a fossil land surface, and which has yielded teeth of several genera of mammals.

A little higher up the hill was seen the Osborne limestone, which is very hard and almost unfossiliferous, in strong contrast to the Upper Headon limestones below. Above this horizon the western face of Headon Hill is grassed over. There was not time to examine the small exposure of Bembridge Limestone on the northern face of the hill or to see the thick deposit of Plateau Gravel on its summit before the party returned to their respective hotels for the night.

On the following day the cliffs of Totland and Colwell Bays were examined. At the south-western end of Totland Bay the cliff showed layers of fine sand and clay of Lower Headon age with many *Erodona*, resting on brown and blue sands, which formed the top of the Headon Hill Sands. High up the cliff was a small area of green marl with a number of characteristic Middle Headon fossils, including *Sinodia* ['*Venus*'] *suborbicularis*. Immediately below the surface soil at one point was a patch of limestone rubble containing fragments of Middle and Upper Headon mollusca mixed with recent land shells. This may be part of the recent tufa recorded by the Geological Survey.

From this point the party moved north-eastwards along the foot of the cliff. The beds dip very gently in this direction, and at the east end of Totland Bay two limestone bands were seen near the top of the Lower Headon Beds, each being crowded with *Limnaea* and other freshwater mollusca. These bands form the reefs off Warden Point at the west end of Colwell Bay. Here, slipped patches of greenish marl with *Corbicula* and *Sinodia* indicated that the Middle Headon Beds were coming in at the top of the cliff once more.

In the centre of Colwell Bay the whole of the low cliff is made up of the Middle Headon Beds, including the well-known '*Venus*' Bed, a grey-blue clay, more sandy above, with a rich fauna predominantly of estuarine fossils though with some freshwater and marine forms. Cutting through this at one point is the Oyster Bed, originally a channel about 15 ft. deep, which slowly became filled with a growth of oysters. Unfortunately the section, normally so rewarding, was covered almost completely by a wash of unfossiliferous material from higher up the cliff. However, sufficient was seen of it to convince the party of its richness and interest.

At the north end of Colwell Bay the Upper Headon Beds reappear. Here they consist of clays and sands, and the thick limestones so conspicuous at Headon Hill are almost unrepresented. In the clays *Erodona* and *Viviparus* were among the mollusca seen, while seeds of waterplants (*Stratiotes*) were noticed. Near Linstone Chine, the Upper Headon Beds are disturbed by a steep anticline only a few yards across; apparently a crumple of local significance only. Here the party left the cliffs and returned to Yarmouth by the main road, pausing only at a vantage point to view the valley of the Yar, which reaches from coast to coast and contains the decapitated remnant of a much larger stream that flowed northward through a gap in the Chalk at Freshwater Gate.

Tea was taken at Yarmouth where on behalf of the President Mr. E. Evans proposed a vote of thanks to the Director.

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JAMAICA GROUP

Field Meeting in the Port Royal Mountains, Jamaica

27 November 1955

Directors: V. A. ZANS and A. D. FRASER

Report by L. J. CHUBB

Received 4 May 1956

THE PARTY, which numbered twenty-five, assembled at the Carib Theatre, Kingston, and under the leadership of V. A. Zans proceeded in eight cars to Papine and thence past Kintyre along the Mavis Bank Road which cuts through the Port Royal Mountains. These mountains consist of an intensely folded belt, between four and five miles wide, trending NW.–SE. between two major thrust-faults, the Wagwater Thrust on the south-west, and the Yallahs Thrust on the north-east. The granodiorite seen in road-cuttings is an extension of the great mass which outcrops widely in the area of Above Rocks, and probably extends underground below Stony Hill, the Red Hills and the Liguanea Plain. It forms the horst against which the Port Royal Mountains have been thrust.

Next the Lower Eocene Purple Conglomerate was seen. At the time when this conglomerate was deposited the area of the Port Royal Mountains formed a gulf into which vast quantities of pebbles and boulders were washed from the high land towards the south-west, including rounded fragments of granodiorite, andesite, and other rocks.

Exposures of the Wagwater Thrust were seen in cuttings in the new road which branches towards Jacks Hill, and, in its windings, crosses the thrust several times. The fault-plane has a considerable hade, and the Purple Conglomerate was seen to be thrust over the granodiorite, with consequent crushing and brecciation. The conglomerate continues along the main road to Gordon Town where it is overlain by a brown sandstone and shale series, the flysch-like Carbonaceous Shale, which here forms the upper part of the Lower Eocene. In some places it yields a fauna similar to that of the Woolwich Beds.

Beyond Gordon Town the site of the Geological Survey boring in the Hog Hole River valley was visited. Members saw exploratory core-drilling in progress, sample cores were studied and the geological structure explained. Near by, a peculiar structure was seen—a kind of diapir—where impure gypsum, intermingled with clay, is squeezed up from below, and penetrates a thick series of purple tuffaceous shales.

Returning to the main road, further exposures were seen of the Eocene sandstone and shale series, dipping south-westward, and about a mile beyond Gordon Town another body of gypsum was studied. This is in the form of a vertical dyke, some 30 ft. thick, which has been squeezed up to an altitude of about 300 ft. above the gypsiferous breccia near the drill-site. Between this point and the Guava Ridge Gap the road is cut chiefly in the Newcastle Porphyry, which here overlies the Eocene conglomerate and shale series. It was regarded by Matley as a sill, but it is discordant, and has rather the form of a nappe, with its roots along the Yallahs Thrust; it caps the hills in this area, and thins and plunges towards the south-west. It is much sheared and weathered, and gives rise to dangerous landslides during heavy rains.

At Guava Ridge Gap, where the road reaches an altitude of over 3000 feet, the conglomerate and shale series were seen again in road-cuttings. They continue to Glade-Orchard, near to which steeply dipping beds of Halberstadt Limestone were observed. Along this stretch of road the Newcastle Porphyry occurs higher up the hill slope.

Lunch was taken at Glade-Orchard, refreshments being kindly provided by Mr. Alastair D. Fraser, Director of Mavis Bank Iron Ore Ltd. Mr. Fraser then conducted the party on a tour of the hillside, where high-grade iron ore, including magnetite and haematite, occurs in veins or lodes up to 32 ft. wide in the country rock of Newcastle Porphyry. This ore was first discovered and mapped by the Geological Survey, and later a magnetometric survey was carried out by Dr. S. A. Vincenz of the Industrial Development Corporation. The arrangement of the veins shows a kind of cone-sheet structure, with the outer veins dipping inwards below the central area, where a network of veins is encountered. The structure is intersected by several faults, indicated by crush-zones in the porphyry and slickensided ore-surfaces, and it is bounded by two major faults both trending NW.–SE. The ore assays about 64% iron, and it is estimated that approximately a million tons are present. Recently Mavis Bank Iron Ore Ltd. has started the first iron-ore mining to be carried out in Jamaica.

From the crest of the ridge above the iron-workings a magnificent view of the Blue Mountain Range was obtained across the Yallahs River which lies about a mile to the north-east. The Blue Mountain massif is separated from the Port Royal Mountain belt by the Yallahs Thrust, which roughly coincides with the river of the same name in this area.

After further refreshments, and a vote of thanks to Mr. Fraser and his assistants, the party returned to Kingston.

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Two Field Meetings at Port Esquivel and Pigeon and Goat Islands, Jamaica

29 January and 4 March 1956

Directors: V. A. ZANS and L. J. CHUBB

Report by L. J. CHUBB

Received 4 May 1956

AT THE FIRST of these meetings the party, consisting of twenty members, drove in five cars from the meeting place in Kingston to Port Esquivel, under the leadership of V. A. Zans. This is the loading port of Alumina Jamaica Ltd., built on the site of Puerto d'Esquivel, a harbour established in 1509 by the first Spanish Governor of Jamaica, Don Juan d'Esquivel, 146 years before the British conquest of the island.

Members were welcomed by Mr. J. B. Leslie, Port Manager, who conducted the party round the modern installation for the bulk loading of alumina into the holds of ships. The alumina, in the form of a white powder, is brought to the port from the company's Kirkvine Works at Shooter's Hill, and carried by a conveyor belt into storage silos. The silos discharge on to a second conveyor which carries the alumina to the loading tower on the pier.

The party then embarked on the launch *Esquivel*, kindly lent by Alumina Jamaica Ltd., and proceeded to Pigeon Island, nearly eight miles south-east of the port, which is a typical coral cay, less than half a mile in diameter, rising from shallow water at the mouth of Old Harbour Bay. It has a broadly crescentic shape, the north-western or leeward side forming a bay nearly 600 yards across with a beautiful beach of fine white coral and *Halimeda* sand. The south-eastern or windward side of the island is composed of coarse loose coralline detritus, with a small proportion of gastropod and lamellibranch shells, forming a rampart rising to a maximum height of 15 feet above sea level, on which a navigation light is situated. The rampart is thrown up during storms which normally come from the south-east. It was the hurricane of 17 August 1951 which was chiefly responsible for the existing accumulation. Among the corals collected were the following:

> *Acropora palmata* (Lamarck), *A. cervicornis* (Lamarck), *A. prolifera* (Lamarck), *Stephanocoenia michelini* Edw. and Haime, *Siderastrea radians*

(Pallas), *S. siderea* (Ellis & Solander), *Porites porites* (Pallas), *P. furcata* Lamarck, *Diploria clivosa* (Ellis & Solander), *D. strigosa* (Dana), *Manicina mayori* Wells, *M. areolata* (Linnaeus), *Montastrea cavernosa* (Linnaeus), *M. annularis* (Ellis & Solander), *Oculina diffusa* Lamarck.

The most abundant of these corals was *Acropora palmata*, fragments o· which constituted more than 50% of the rampart on the windward side *Millepora alcicornis* Linnaeus was also found. From the high south-eastern end of the island the rampart continues round the flanks at a decreasing altitude, and ends in spits at the two ends of the north-western bay. A small salt-water lagoon occupies the central part of the crescent thus formed.

After lunch the party re-embarked and proceeded to Great Goat Island. This is entirely different from Pigeon Island in consisting of Tertiary limestone forming a hill 250 feet high. A landing was made with difficulty on the south-west side and members walked through the mangrove swamps and over the coastal plain to the limestone exposures on the slopes of the hill. Several Lower Miocene foraminifera were found including the following species:

Gypsina globulus (Reuss), *G. pilaris* (Brady), *Operculinoides* aff. *tuxpanicus* Vaughan & Cole.

A projected visit to Little Goat Island had to be abandoned, owing to lack of time. On returning to Port Esquivel the party was hospitably entertained by Mr. and Mrs. J. B. Leslie.

As the number of members attending this meeting had to be limited to twenty (i.e. the capacity of the launch), the trip was repeated on 4 March, under the leadership of L. J. Chubb. Fifteen members and friends attended. The same programme was followed, but Great Goat Island was approached from the north-east. There are no reefs on this side, so the launch was able to anchor near the shore and landing was effected at a gap in the mangrove thickets. The slope, apparently a dip-slope of Tertiary white limestone, was ascended to a considerable height. No fossils were found but many small karst features were observed such as sink-holes, grikes and fretted surfaces.

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